Development of the Total Maximum Daily Load (TMDL) for Fecal Coliform Bacteria in Moore's Creek, Albemarle County, Virginia

Submitted by:

Virginia Department of Environmental Quality

Virginia Department of Conservation and Recreation

Prepared by:

Teresa B. Culver, Yanbing Jia, Rajat Tikoo,

and Jared Simsic

of the

Department of Civil Engineering

University of Virginia, Charlottesville, Virginia

And

Rochelle Garwood

of the

Thomas Jefferson Planning District Commission

Charlottesville, Virginia

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Project Personnel

Department of Civil Engineering, University of Virginia

Teresa B. Culver, Associate Professor

Yanbing Jia, Research Assistant

Rajat Tikoo, Research Assistant

Jared Simsic, Research Assistant

Thomas Jefferson Planning District Commission

Rochelle Garwood, Planner

Chris Gensic, Planner

Harrison Rue, Director

Department of Environmental Quality

Sandra Talarovich Mueller, Regional TMDL Coordinator, Valley Regional Office

David Lazarus, Water Quality Assessment Office, Richmond

Department of Conservation and Recreation

William Keeling, TMDL Project Coordinator, Richmond, Virginia

Michael Bowman, James River Watershed Manager

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Table of Contents

List of Tables

List of Figures

Executive Summary

Introduction

The Moore's Creek watershed (VAV-H28R) is a sub-watershed of the Upper Rivanna River Watershed. The watershed drains 34.92 sq. miles of Albemarle County, Virginia, including the southern portion of the City of Charlottesville. Moore's Creek flows approximately 11 miles from its source in the Ragged Mountains to its confluence with the Rivanna River in Charlottesville. The watershed is predominantly forested, with residential areas, grasslands, and urban areas the other major land uses.

Water quality sampling on Moore's Creek between August 1991 and January 2002 found that 14.5% of the water samples violated the instantaneous fecal coliform standard of 1000 cfu/100 ml and that the 30-day geometric mean standard of 200 cfu/100 ml was violated 59% of the time. Due to the high percentages of violations (over 10%) the stream was placed on Virginia's 1998 303(d) list of impaired waters. A 6.37-mile reach from the intersection of U.S. Route 29 and County Route 1106 to the confluence of the Rivanna River was listed as impaired due to elevated levels of fecal coliform bacteria.

In response to the impairment, a Total Maximum Daily Load (TMDL) for fecal coliform bacteria has been developed for Moore's Creek. The TMDL takes into account all sources of fecal coliform bacteria, including background sources, considers critical conditions and seasonal variability, and includes a margin of safety. Community participation has been encouraged throughout the process. Details are reviewed below.

Critical Conditions

An analysis of the water quality monitoring record in Moore's Creek shows that violations of 30-day geometric mean standard occur more than 10% of the time in every month of the year and that violations of the instantaneous standard have also been observed in every month of year. Furthermore, violations of the fecal coliform standard occur during both dry and wet weather events. Therefore, the critical condition for fecal coliform bacteria in Moore's Creek is the typical hydrologic year. Special consideration will be given to the extremes of flow, including periods of very low flows and large storm events.

Sources and Loading of Fecal Coliform Bacteria

Fecal coliform bacteria originate from all warm-blooded animals and can contaminate a stream from point and nonpoint sources. In the Moore's Creek watershed, fecal coliform bacteria are discharged from two point sources, the Moore's Creek Advanced Wastewater Treatment Plant, operated by the Rivanna Water and Sewer Authority, and Southwood Mobile Home park, which operates its own package treatment plant. The average fecal coliform concentration in the Moore's Creek Plant effluent is 17 cfu/100 ml, and the average volume of outflow is 11 million gallons per day. This facility discharges just downstream from the state water quality monitoring site. The Southwood Mobile Home Park is located along Biscuit Run upstream of the water quality monitoring site. Poorly treated waste was observed around the outfall from the Southwood Mobile Home Park plant in February 2002, although there is no record of chronic permit violations from this plant. The plant has a permit limit of 200 cfu/100 ml and an average outflow of 39,000 gallons per day. The Virginia Department of Environmental Quality (VADEQ) water quality monitoring staff is currently investigating waste solids in the receiving stream near the outfall of Southwood. VADEQ will manage this problem through compliance assistance or enforcement. Nonpoint sources include background wildlife, livestock, pets, and humans. Major wildlife species are deer, geese, raccoons, muskrat, and beaver. Wildlife loads were applied to both the land surface and as direct input to the stream. Although agriculture is not intensive in the Moore's Creek watershed, cattle, horses, and goats contributed to the fecal coliform load to the land. In addition, cattle had access to the stream at two sites, where direct cattle loads to the stream can occur. Pet loads are dominated by dogs. Human nonpoint source loads come from failing septic systems, straight pipes to the stream, and leakage from sanitary sewers. A bacterial source tracking study concluded that the system was dominated by wildlife impacts, followed by livestock. While human sources did not dominate the samples in the bacterial source tracking study, human bacteria were consistently detected.

Modeling

The BASINS Nonpoint Source Model (NPSM) and the Hydrologic Simulation Program-FORTRAN (HSPF) were used to simulate flow and the fate and transport of fecal coliform bacteria in the Moore's Creek watershed. These models incorporate temporal and spatial variability within the watershed.

Due to a minimal amount of flow observations from Moore's Creek, an equivalent watershed approach and synthetic flow generation were used to calibrate the hydrological component of the models. The Buck Mountain Run watershed within the Rivanna drainage system was selected as an equivalent watershed. The HSPF/NPSM model was calibrated to the Buck Mountain Run watershed, which is similar although a bit less developed than the Moore's Creek watershed, for the five-year period between 10/1992-9/1997. A synthetic flow generator that combined an artificial neural network and a maintenance of variance approach was developed and demonstrated on the Buck Mountain Run watershed.

The synthetic flow generator was then applied to the Moore's Creek system to create flow predictions for the period over which significant water quality and flow observations exist (10/1996-8/2001). The synthetic flow predictions not only accurately reproduced the observed flows on Moore's Creek, but also provided a continuous calibration target for the NPSM/HSPF model on Moore's Creek. NPSM/HSPF parameters for the Buck Mountain Run watershed were adjusted to accurately reproduce the synthetic flows for the 5-year period. The water quality model was then calibrated to the observed fecal coliform concentrations over the same 5-year period. The fecal coliform loads that were applied directly to the stream and to the land surface were calculated on a monthly basis to account for seasonal variability in wildlife populations and the varying time that cattle will spend in the stream.

Results for Existing Conditions

Water quality predictions during the calibration period predicted that under current conditions the instantaneous standard would be violated 18% of the time and the 30-day geometric mean criterion of 200 cfu/100ml would be violated 62.8% of the time. Of the bacteria that reached the stream, 40.1% were from wildlife, 34.1% from livestock, 19.4% from dogs, and 6.4% from human sources, although the relative proportions of these sources may shift, dependent on whether the stream was at low or high flows and with season.

Margin of Safety

The fecal coliform load in the TMDL is divided into three categories. One is the margin of safety (MOS). A margin of safety will be explicitly added by achieving concentrations 5% below the 30-day geometric mean criterion of 200 cfu/100 ml. The remaining allowable 190 cfu/100ml is divided between the allowable loading from point sources (termed the waste load allocation, WLA) and the allowable loading from nonpoint sources (termed the load allocation, LA).

TMDL Allocation Scenarios

Establishment of a TMDL is meant to provide a loading that will be protective of water quality in the future. Thus, future conditions were used for determination of the allowable load. A human population increase and land use changes were assumed, consistent with the current population growth rate of the county and the county growth area plan.

For the base case for future land-based nonpoint source loads, the fecal coliform loading rates (counts/acre/month) for most land uses were held constant with the rates from the current conditions. The exception was for grasslands, which included pastures. Due to a rapid decline in livestock populations, the loading rate used for grasslands during the calibration period was not representative of the anticipated loading in the future. Therefore, the loading rate for grasslands for the base case was modified to be consistent with the 2002 population and distribution of livestock within the watershed. Overall, the grassland loading rates under future conditions averaged 53% of those used during the calibration period.

For the base case, future loads of coliform bacteria deposited directly in Moore’s Creek will come from four sources: the two point sources and cattle and wildlife in the stream. Both point sources were modeled as discharging at their maximum permitted concentration of 200 cfu/100 ml and their expected average outflows. With the increase in population, the future average outflow from the Moore's Creek wastewater treatment plant increases to 12 million gallons per day, while the flow volume from Southwood facility remains unchanged. The direct load from cattle in stream was also reduced due to loss of livestock from one of the stream access areas. Wildlife deposition directly to the stream was assumed unchanged from that determined for the present case simulations. Although some modifications to the wildlife populations and distribution are expected to be induced by land use alterations, some wildlife populations will decrease while others will increase. Thus changes in wildlife numbers tend to offset, leaving only a small impact, relative to the model uncertainty, on the total wildlife load deposited directly in the stream.

TMDL allocation scenarios were then generated by reducing the base case loads. The first step in building an allocation scenario was removal of all non-permitted human bacterial loads (straight pipes, sewer system leakage, and failing septic systems) and exclusion of cattle from the stream. These changes alone are insufficient to meet the TMDL goal. However, since untreated human waste should not be reaching the stream and allowing livestock access to the stream is an inappropriate management practice, these two steps were assumed in all other scenarios. Furthermore, adding extreme reductions in the remaining land-based loads from human activities was insufficient to meet the TMDL target.

Therefore a TMDL allocation that reduced both the direct wildlife loads to stream and the remaining land-based nonpoint source loads was developed. Reduction levels varied by subwatershed and by land use. Table 1 shows the recommended load reductions to meet the TMDL goal. As in previous scenarios, all non-permitted human sources were removed and cattle were removed from the stream. Some subwatersheds show zero reductions in one or more of these sources simply because there were no such sources in the subwatershed under base case conditions. Residential reductions were assigned to developed subwatersheds along or near the main stem of Moore's Creek. Reductions in grassland loads were assigned to subwatersheds that still held significant numbers of livestock. The high percentage reduction to grasslands in subwatershed 9, assumes that the feral goat population will be removed and best management practices will be put in place around the stockyard. For subwatersheds with a significant urban area, urban contributions were reduced from 45% to 50%, with the highest reductions assigned to the subwatersheds near the main stem of Moore's Creek.

Table 1. TMDL load reductions for the Moore's Creek watershed. (SW# indicates subwatershed number.)

	Percentage Reductions in Contributions from:									
						Other NPS: By Land Use				
SW#	Direct Cattle	Straight Pipe	Septic NPS	Sewer Leak-age	Direct Wildlife	Forest	Low-Density Resid.	Med-Density Resid.	Grass-land	Urban
1	0	100	100	100	40	0	0	0	0	45
2	0	0	100	0	40	0	0	0	0	45
3	100	100	100	0	40	0	0	0	30	45
4	0	0	0	0	40	0	0	0	0	0
5	0	0	100	100	40	0	30	30	30	50
6	0	100	100	100	40	0	40	40	30	45
7	0	100	100	0	40	0	0	0	30	0
8	0	0	100	0	40	0	0	0	30	0
9	0	0	100	100	40	0	50	50	85	50
10	0	0	0	100	40	0	50	50	0	50
11	0	0	0	100	40	0	50	50	0	50

The corresponding TMDL load allocations for the Moore's Creek watershed are shown in Table 2. The allocations are based on the total contributions to the stream. Each point source is allocated its permitted waste load allocation (WLA). The contribution from the Southwood Mobile Home Park (VA0029955) load, at 200 cfu/100 ml and an average outflow of 39,000 gallons/day, is shown under WLA(SW), while the contribution from the Moore's Creek Advanced Wastewater Treatment Plant (VA0025518) load, at 200 cfu/100 ml and an average flow of 12 million gallons per day, is shown under WLA(MC). These allocations require no reduction from the permitted point source loads, although any permit violations are assumed eliminated. Table 2 also shows the total allocation to nonpoint sources (ΣLA) and the load reserved as a margin of safety (MOS). To meet this TMDL, the required reduction of all nonpoint source contributions (direct to stream and land based; human controlled and background) is 31.8% compared to current contributions or 34.6% compared to the base case future contributions.

Table 2: TMDL load allocations (cfu/day)

WLA(SW)	WLA(MC)	ΣLA	MOS[a]	TMDL
0.01×10^{13}	3.30×10^{13}	61.41×10^{13}	3.41×10^{13}	68.13×10^{13}

[a]Five percent of the TMDL

The selected allocation scenario described in Table 1 may be conservative if the upstream point source (Southwood) regularly discharges at levels below its maximum permitted level. Since the allocation assumes that the point sources are discharging at their maximum permitted levels, any excess load assigned to the point source takes away available loading from other sources. Thus, the reductions required from wildlife and the other nonpoint source land loads may need adjustment as staged implementation occurs and if monitoring data reflects obtainment of water quality standards.

Implementation and Reasonable Assurance

Section 303(d) of the Clean Water Act does not specify an implementation process for TMDLs. However, Virginia's 1997 Water Quality Monitoring, Information, and Restoration Act directs the VADEQ to develop a plan for the expeditious implementation of TMDLs. VADEQ plans to incorporate TMDL implementation plans as part of the 303(e) Water Quality Management Plans (WQMP). In a recent Memorandum of Understanding between the VADEQ and U.S. Environmental Protection Agency, the VADEQ has committed to updating the WQMPs. Thus, the WQMP will serve not only as a repository of TMDLs, but also maintain a record of the current progress on TMDL implementation plans. Each implementation plan will contain expected dates of achievement of water quality objectives, estimated costs, and a description of availability of funds for implementation of corrective actions.

Implementation of the management plan to meet the TMDL will occur in stages. A potential Phase 1 goal could be reduction in the violations of the 30-day geometric mean criterion to less than 10% of the time. Removal of all straight pipes and any episodic permit violations at the Southwood Treatment plant would reduce the violations of the 30-day geometric mean standard to 5.0% of the time.

Public Participation

A community TMDL advisory committee was convened by the Thomas Jefferson Planning Disctrict Commission (TJPDC). Ultimately 12 people were named to the community advisory committee by the TJPDC, including representatives from Albemarle County, the City of Charlottesville, the Rivanna Water and Sewer Authority, the Thomas Jefferson Soil and Water Conservation District, the Albemarle County Farm Bureau, the Southern Environmental Law Center, the Fry's Springs and Belmont Neighborhood Associations, and several other interested citizens. The community advisory committee met on September 21, 2001, November 27, 2001, February 12, 2002, and March 26, 2002. The advisory committee reviewed and provided feedback on the preliminary loading assumptions and on the final TMDL draft report. Their suggestions were incorporated into the loading assumptions during the calibration of the water quality model and into the final TMDL report.

In addition, in compliance with the U.S. Environmental Protection Agency requirement for public participation, three public meetings were organized and conducted as part of the formal TMDL process. Public meetings were held in Charlottesville on June 7, 2001, November 15, 2001, and March 25, 2002. The first two meetings introduced and reviewed the current status of the TMDL development, while the third meeting presented the draft TMDL report.

Watershed stakeholders will have opportunities to continue to provide input and participate in the development of implementation plans for the TMDL. Regional and local offices of the VADEQ and Virginia Department of Conservation and Recreation, along with other cooperating agencies, will continue to provide support during the plan development and implementation stages.

Chapter 1: Introduction

1.1 Overview of the Moore's Creek Impairment

The Moore's Creek watershed drains 34.92 sq. miles of Albemarle County, Virginia, including the southern portion of the City of Charlottesville. Moore's Creek discharges into the Rivanna River shortly downstream from the Moore's Creek Advanced Wastewater Treatment plant (WWTP). Figure 1.1 shows the study area. The watershed is predominantly forested, with residential areas, grasslands, and urban areas making up the other major land uses. Land uses are described in more detail in Section 3.4.

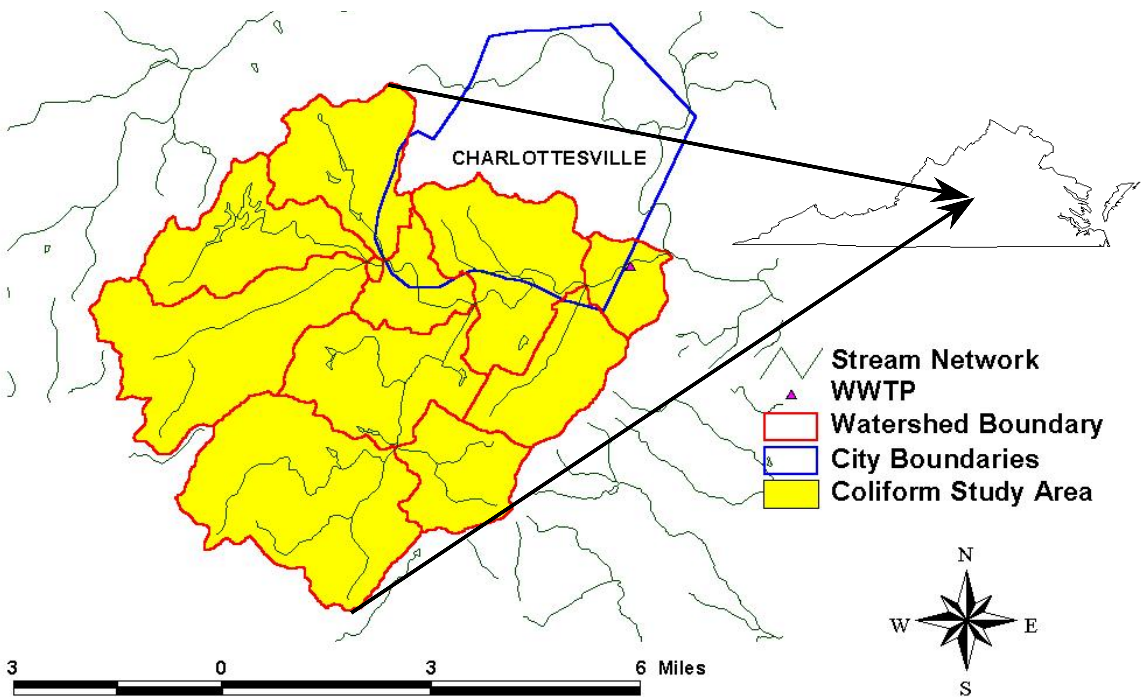

Figure 1.1 The Moore's Creek watershed.

Moore's Creek, like all waters in Virginia, is designated for the following uses (9 VAC 25-260-10): recreation (e.g. swimming and boating); the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife habitat, and the protection of edible and marketable natural resources. If a waterbody cannot fully support its designated uses, it is considered impaired.

Fecal coliform bacteria are found in the intestinal tracts and fecal matter of warm-blooded animals. Fecal matter, which is very high in fecal coliform bacteria, may be discharged into the stream from point and non-point sources. While fecal coliform bacteria are typically not pathogenic, they are used as an indicator species for pathogens. The more fecal coliform bacteria in a water sample, the more likely the water sample contains pathogens, which may also be present in fecal matter. For recreational uses, health risks increase as the fecal coliform concentration in the waterbody increases.

States are required by the Clean Water Act to identify and report to the U.S. Environmental Protection Agency (USEPA) their water quality-impaired waters. The Virginia Department of Environmental Quality (VADEQ) has found sufficient exceedances of the water quality standard for fecal coliform bacteria at its water quality monitoring station on Moore's Creek (Station ID 2-MSC000.60) to conclude that the swimmable use was only partially supported. Thus, in 1998, Moore's Creek was placed on Virginia's 303(d) List of Impaired Waters (VADEQ 1998). A 6.37-mile reach from the intersection of U.S. Route 29 and County Route 1106 to the confluence of the Rivanna River was listed as impaired due to elevated levels of fecal coliform bacteria.

1.2 Overview of the Total Maximum Daily Load Process

Section 303(d) of the Clean Water Act and the USEPA's Water Quality Management and Planning Regulation (40 CFR Part 130) require states to develop total maximum daily loads (TMDLs) for an impaired waterbody. A TMDL is the greatest amount of a pollutant that a waterbody can receive without violating applicable water quality standards. Background concentrations, point source loadings, and nonpoint source loadings are considered. Furthermore, a fraction of the allowable load is reserved for a margin of safety to account for uncertainty and variability in TMDL development. Critical conditions must be identified, and then analysis and management alternatives must consider these critical conditions. Through the TMDL process, states can establish water-quality based controls to reduce pollution and restore the quality of their water resources (USEPA 1991). Thus, a TMDL should set bounds for long-term sustainable watershed management. A detailed description of the TMDL program can be found at the USEPA web site (2002).

Chapter 2: Water Quality in Moore’s Creek: Current and Future Conditions

2.0 Water Quality Standards

According to Virginia Water Quality Standards (9 VAC 25-260-5), the term “water quality standards” means provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water, and serve the purposes of the State Water Control Law (§62.1-44.2 et seq. of the Code of Virginia) and the federal Clean Water Act (33 USC §1251 et seq.).

2.0.1 Designated Uses

According to Virginia Water Quality Standards (9 VAC 25-260-10), “all state waters are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)”.

2.0.2 Applicable Water Quality Criteria

For a non-shellfish supporting waterbody to be in compliance with Virginia fecal coliform standards for contact recreational use, Virginia Department of Environmental Quality (VADEQ) specifies the following criteria (9 VAC 25-260-170):

> “…the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 mL at any time.”

Based on the sampling frequency, only one criterion is applied to a particular datum or data set (9 VAC 25-260-170). If the sampling frequency is one sample or less per 30 days, the instantaneous criterion is applied; for a higher sampling frequency, the geometric criterion is applied. The geometric mean of N samples, where each sample value is indicated by a lower case letter, is calculated as follows:

$$geomean = (a * b * c * d ...)^{1/N}$$

The geometric mean is a useful indicator of the representative magnitude of a set of values when the values may vary by orders of magnitude. Very high variability in sample values is expected in fecal coliform sampling. If the applicable criterion for a waterbody is exceeded more than 10% of the time, the waterbody is classified as impaired and a TMDL must be developed and implemented to bring the waterbody into compliance with the water quality criterion.

2.1 Potential Changes in the Applicable Water Quality Standards

The VADEQ and Virginia Department of Conservation and Recreation have developed fecal coliform TMDLs for a number of impaired waters in the Commonwealth (VADEQ 2002). In the process, some apparent inconsistencies between the Commonwealth's fecal coliform criteria and the natural conditions of the stream have become evident. For instance, in some of the streams, fecal coliform bacteria counts contributed by wildlife result in violations of water quality standards, particularly during base flow conditions. Wildlife densities obtained from the Department of Game and Inland Fisheries and analysis or "typing" of the fecal coliform bacteria show that the high densities of muskrat, beaver, and waterfowl are partially responsible for the stream impairments due to elevated levels of fecal coliform bacteria.

In order to address high wildlife contributions and other issues, the Commonwealth is currently reviewing its water quality standards with respect to fecal coliform bacteria. Issues under review are designated uses and indicator species. In addition, the U.S. Environmental Protection Agency (USEPA) allows the States the option of adopting site-specific criteria based on natural background levels of fecal coliform bacteria. The State must demonstrate that the source of fecal contamination is natural and uncontrollable by effluent limitations and best management practices. Each of these possible modifications in the applicable water quality standard is described below.

2.1.1 Designated Uses

All waters in the Commonwealth have been designated as "primary contact" for the swimming use regardless of size, depth, location, water quality or actual use. The fecal coliform bacteria standard is described in 9 VAC 25-260-170 and in Section 2.0 of this report. This standard is to be met during all stream flow levels and was established to protect bathers from ingestion of potentially harmful bacteria. However, many headwater streams are small and shallow during base flow conditions when surface runoff has minimal influence on stream flow. Even in pools, these shallow streams do not allow full body immersion during periods of base flow. In larger streams, lack of public access often precludes the swimming use. In the TMDL public participation process, the residents in these watersheds often report that "people do not swim in this stream."

It is obvious that many streams within the state are not used for recreational purposes. In many cases, insufficient depth of the streams as well as wildlife impacts prevent the attainment of the primary water quality standard. Recognizing that all waters in the Commonwealth are not used extensively for swimming, the Commonwealth is considering re-designation of the swimming use for secondary contact in cases of: 1) natural contamination by wildlife, 2) small stream size and 3) lack of accessibility to children, as well as due to widespread socio-economic impacts resulting from the cost of improving a stream to a "swimmable" status.

The re-designation of the current swimming use in a stream will require the completion of a Use Attainability Analysis (UAA). A UAA is a structured scientific assessment of the factors affecting the attainment of the use which may include physical, chemical, biological, and economic factors as described in the federal regulations under 40 CFR §131.10(g). The stakeholders in the watershed, Virginia, and USEPA will have an opportunity to comment on these special studies.

2.1.2 Indicator Species

The USEPA has recommended that all States adopt an *E. coli* or enterococci standard for fresh water and enterococci criteria for marine waters by 2003. USEPA is pursuing the States' adoptions of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and enterococci) and the incidence of gastrointestinal illness than with fecal coliform bacteria. *E. coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. The adoption of the *E. coli* and enterococci standard is scheduled for 2002 in Virginia.

2.1.3 Wildlife Contributions and Site-specific Criteria

In some streams for which TMDLs have been developed, even the removal of all of the sources of fecal coliform (other than wildlife) does not allow the stream to attain standards. TMDL allocation reductions of this magnitude are not realistic and do not meet USEPA's guidance for reasonable assurance. Based on water quality modeling, many of these streams will not be able to attain standards without some reduction in wildlife. **Virginia and USEPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards.** This is obviously an impractical action. Clearly, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL. If, after implementation of reasonable and practicable control actions, violations of the water quality standard persist due to wildlife loadings, then a UAA (as described in Section 2.1.1) may become necessary.

2.2 Water quality monitoring on Moore's Creek

There are two primary sources of fecal coliform monitoring data for Moore's Creek. The VADEQ performs random quarterly sampling to determine the water quality status of the creek. In addition, the Rivanna Water and Sewer Authority (RWSA) samples the stream weekly. The sampling is in compliance with its Virginia Pollution Discharge Elimination System (VPDES) permit for the Moore's Creek Advanced Wastewater Treatment Plant (WWTP), which discharges into Moore's Creek 0.6 miles upstream of the confluence with the Rivanna River. The RWSA samples the creek upstream and downstream of its discharge point. The upstream sampling point is also the VADEQ sampling point and the location of the staff gauge to monitor flow on the creek. The location of the WWTP, which is also the VADEQ and RWSA sampling point and staff gauge location, is shown in Figure 1.1.

2.2.1 VADEQ monitoring

Forty-five water samples were collected from Moore's Creek between August 1991 and January 2002 at the bridge at the RWSA wastewater treatment plant. The results of this sampling are given in Table 2.1. The number of bacteria in the stream is measured in terms of the number of colony-forming units (cfu) per 100 ml of water. As can be seen, more than 10% of the samples have violated the instantaneous criterion, thus Moore's Creek is considered impaired with respect to fecal coliform bacteria. Sampling frequency does not allow for calculation of the 30-day geometric mean.

Table 2.1 VADEQ sampling on Moore's Creek

Number of samples	Maximum Value	% violations of instantaneous criterion	% violations of 30-day geometric mean criterion
45	2600 cfu/100 ml	20%	--

2.2.2 RWSA monitoring

Table 2.2 summarizes the results of the RWSA sampling, upstream of their effluent discharge point, between October 1997 and January 2002. Their sampling shows violations of both the instantaneous criterion and the 30-day geometric mean criterion.

Table 2.2 RWSA sampling on Moore's Creek

Number of samples	Maximum Value	% violations of instantaneous criterion	% violations of 30-day geometric mean criterion
218	200,000 cfu/100 ml	13%	59%

2.3 Critical Conditions

The VADEQ samples and the RWSA samples summarized in Section 2.2 are combined for an analysis of critical conditions controlling when violations of the water quality standards are likely to occur. Combination of these two monitoring programs allows for

4 to 5 running estimates of the 30-day geometric mean per month between October 1997 and January 2002. Figure 2.1 shows the percentage of estimates per month that exceed the 30-day geometric mean criterion of 200 cfu/100 ml. As can be seen, the 30-day geometric mean criterion is violated more than 10% of the time in every month of the year, and continual violations of this standard occur between June and September. Violations of the instantaneous standard have also been observed in every month of the year. Furthermore, nine of the ten highest observed fecal coliform concentrations occur between June and mid-October.

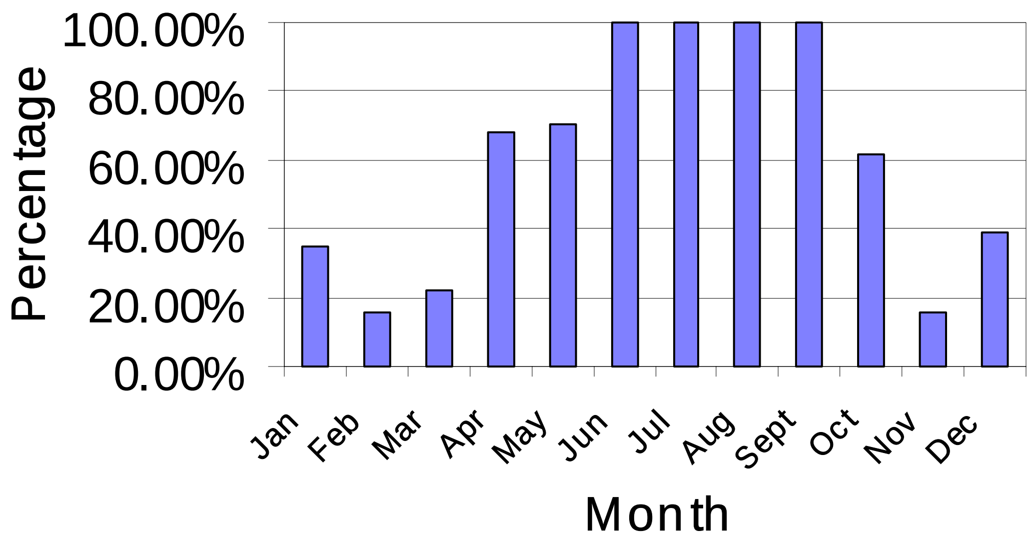

Figure 2.1. Percentage violations of the 30-day geometric mean standard in Moore's Creek.

When in-stream coliform concentrations between 9/1991 and 8/2001 are plotted against the estimated stream flow (Figure 2.2), one can see that stream flow is a poor predictor of coliform levels, except during the extremes of flow. All samples collected during the lowest 2.5% of flows had fecal coliform levels consistently near or above 200 cfu/100 ml, suggesting that violations of the 30-day geometric mean criterion would be chronic during extended periods of very low flow. Furthermore, all samples collected during the highest 1.7% of flows violated the instantaneous standard of 1000 cfu/100 ml. However, during the remaining 96% of the flows, flow is not correlated with the fecal coliform levels.

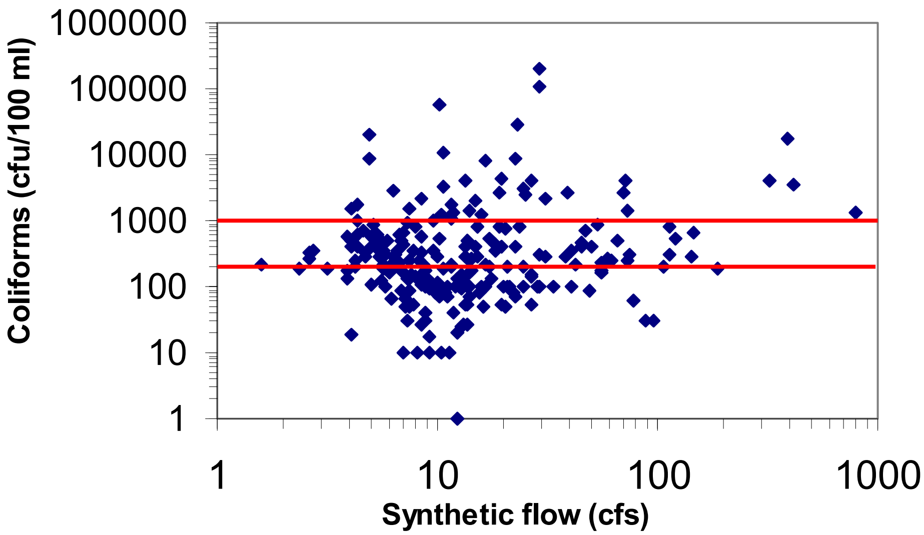

Figure 2.2. Relationship between fecal coliform concentrations and the synthetic streamflow in Moore's Creek. (Upper and lower lines are the instantaneous and 30-day geometric mean criteria, respectively).

In general, the daily rainfall and in-stream concentration are not strongly correlated. However, the violations of the instantaneous standard are typically associated with rainfall events. Of the thirty-seven violations of the instantaneous standard that have been recorded between 9/1991 and 8/2001, 73% were associated with rainfall ending on the day of or the day preceding the sampling date. The largest storm events (greater than 2 inches of precipitation occurring during a three-day period ending on the sampling date) are likely to cause violations of the instantaneous standard; 6 of 7 samples collected during these large events had violations of the instantaneous standard. However, it must be cautioned that many storm events did not cause violations to occur.

Since violations occur throughout the year and during both dry and wet weather events, the critical condition for fecal coliform bacteria in Moore's Creek is the typical hydrologic year. Special consideration will be given to the extremes of flow, including periods of very low flows and large storm events.

2.4 TMDL Water Quality Goal

The goal of the TMDL analysis is to establish the pollutant loading that a stream can assimilate and still meet water quality standards. In general, the Virginia water quality standards are used as a measure of whether water quality is sufficiently protected. As described in Section 2.0, the Commonwealth of Virginia has established two water quality criteria for fecal coliform bacteria, an instantaneous criterion and a 30-day geometric mean criterion. As will be described in Chapters 5 and 6, computer simulation of the watershed will be used in the development of the fecal coliform bacteria TMDL for Moore's Creek. This allows for predictions of the daily concentration of fecal coliform bacteria in Moore's Creek, analogous to daily sample collection. The Moore's Creek TMDL is required to meet the geometric mean criterion, since computer modeling allows for running estimates of the 30-day geometric mean. Thus, the goal of this TMDL will be to ensure that the 30-day geometric mean of the concentration of fecal coliform bacteria in Moore's Creek remains below 200 cfu/100 ml.

The TMDL development process must account for seasonal and annual variations in precipitation, flow, and pollutant contributions and for changes in land use. Such an approach ensures that TMDLs, when implemented, do not result in violations under a wide variety of scenarios that affect fecal coliform loading. A multi-year analysis period will be used to cover the range of conditions that can typically be expected in the Moore's Creek watershed. Furthermore, a margin of safety must be incorporated to allow for uncertainty in the analysis. To due so, an explicit 5% margin of safety will be used, so that the instream concentrations will remain 5% below the geometric standard. Thus the model predictions for instream fecal coliform concentrations must be at or below 190 cfu/100 ml.

Chapter 3: Watershed Characterization

3.1 Water Resources

The Moore's Creek watershed (HUC: VAV-H28R) is a sub-watershed of the Upper Rivanna River Watershed and is located in Albemarle County, Virginia. The Rivanna River is part of the James River drainage. Moore's Creek flows approximately 11 miles from its source in the Ragged Mountains to its confluence with the Rivanna River in Charlottesville (Dewberry & Davis 1996). Overall, there are approximately 37.5 miles of stream within the Moore's Creek stream network, with the main branch streams being Biscuit Run, Cow Branch and Morey Creek. (Figure 3.1). Based on this stream network, the watershed was divided into 11 subwatersheds, as shown in Figure 3.2. The Subwatershed Numbers (SW#) in all subsequent tables correspond to the numbered subwatersheds shown in Figure 3.2. The Ragged Mountain Reservoir (Figure 3.1) for public drinking water supply is located within the watershed. The reservoir consists of the Upper Ragged Mountain Dam and the Lower Ragged Mountain Dam having capacities of 757 acre-feet and 1479 acre-feet, respectively (Dewberry & Davis 1996). The normal storage volumes are about 128 acre-feet and 50 acre-feet respectively (Dewberry & Davis 1996). Water is transferred from the Sugar Hollow Reservoir, which is outside of the Moore's Creek watershed, for temporary storage in the Ragged Mountain Reservoir and then withdrawn to supply drinking water to the City of Charlottesville. The net change in water volume in the Moore's Creek drainage caused by this water transfer then withdrawal is negligible. There are also small unnamed lakes in subwatersheds 1, 6, 7 and 10 with areas of approximately 15.6, 22.8, 5.7 and 9.3 acres, respectively.

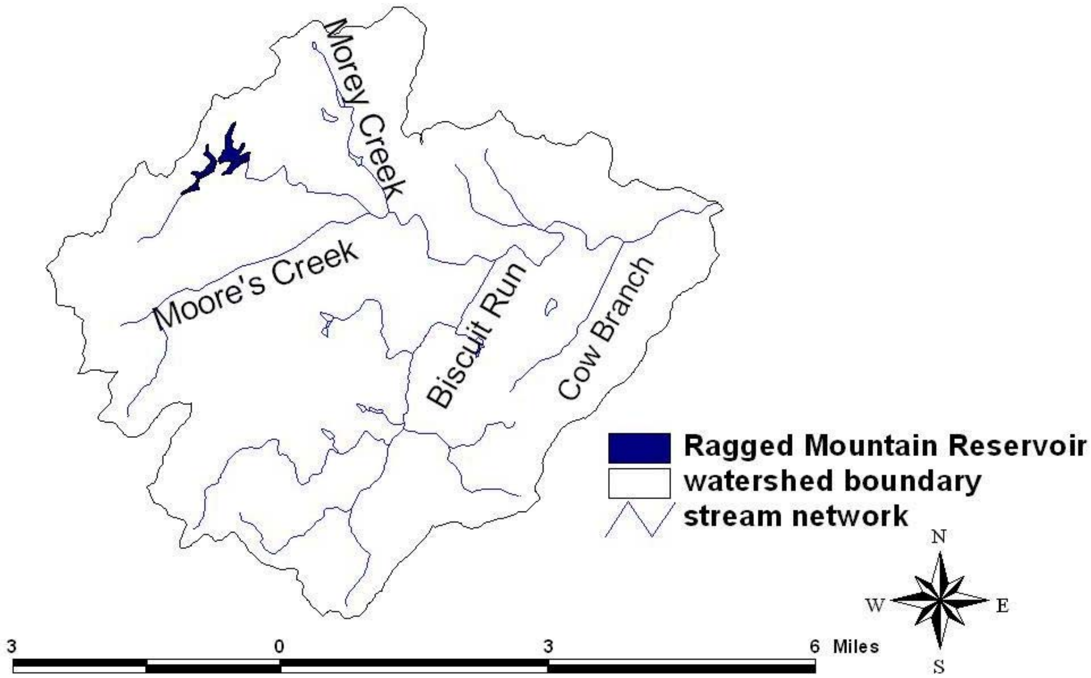

Figure 3.1 Stream network of the Moore's Creek watershed.

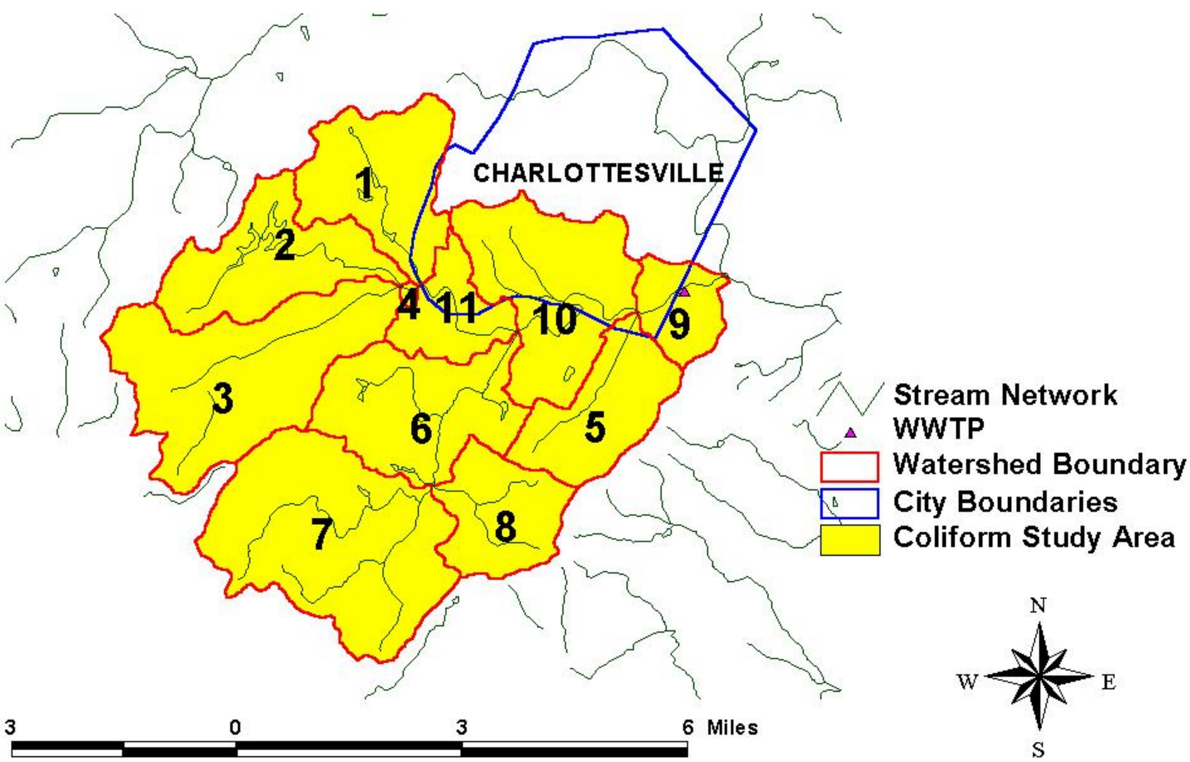

Figure 3.2. Subwatersheds of the Moore's Creek watershed.

3.2 Soils and Geography

Approximately one third of the Moore's Creek watershed lies within the Blue Ridge physiographic province and the remaining two thirds lie within the Piedmont physiographic province of Virginia. Elevations range from 400 feet to 1545 feet above sea level, with an average elevation of 680 feet (USEPA 1998). The upland areas of the Blue Ridge within the Moore's Creek watershed are comprised of the Parker-Chester-Porters soils mapping units which are deep, excessively drained and well drained soils that have stones on the surface and a loamy subsoil; formed in material weathered from granite and gneiss (Soil Conservation Service, 1985). Colluvial terraces, within both the Blue Ridge and on the Piedmont, include the Braddock-Thurmont-Unison soil map units, which are deep well-drained soils with a clayey or loamy subsoil, formed from colluvium (Soil Conservation Service, 1985). The remaining portions of the Moore's Creek watershed, within the Piedmont physiographic province, contain the Haysville-Ashe-Chester and Elioak-Hazel-Glenelg soil mapping units (Soil Conservation Service, 1985). The Haysville-Ashe-Chester soils are deep to moderately deep, and well-drained to somewhat excessively drained soils that have a clayey or loamy subsoil, formed in material weathered from granite and gneiss (Soil Conservation Service, 1985). The Elioak-Hazel-Glenelg soils are deep to moderately deep and well drained to excessively drained soils that have a clayey or loamy subsoil, formed in material weathered from quartz and mica schist (Soil Conservation Service, 1985).

3.3 Climate

Annual precipitation is about 45 inches and is evenly distributed throughout the year (Dewberry & Davis 1996). The temperatures range from an average around 37°F in January to an average of 76°F in July (Dewberry & Davis 1996).

3.4 Land Use

A digital map of the land use coverage for the watershed was prepared by the Thomas Jefferson Planning District Commission (TJPDC). The land use coverage is primarily based on aerial photographs taken in March 2000. This information was supplemented by an earlier land use study by the TJPDC that was completed in 1993 and utilized some information dating back as far as 1987 (Duncan, undated). The TJPDC identified 21 different land use classes within the watershed. These classes were then grouped into six major land uses, based on similarities in hydrologic properties and fecal coliform bacteria loads (Table 3.1). Forest (56.2%) and grasslands (14.7%) are the dominant land uses in the watershed. The remainder of the watershed is primarily low-density residential (9.8%), medium-density residential (8.6%), and urban (9.9%). These land uses, however, are not distributed equally within the watershed, due to development around the City of Charlottesville. Table 3.2 shows the distribution of the major land uses by subwatershed.

Table 3.1. Consolidation of land use classes and percentage of watershed. Original land use classes are indicated by standard numerical codes for land uses in Virginia.

Land use in TMDL	Percentage	Original Land use classes
Forest	56.2%	4 – Forest 461-Grazed forest (agriculture) 6 - Wetlands, including forested
Low-Density Residential	9.8%	111 - Low Density Residential (.2 - 2 dwelling units/acre) 118 - Wooded Residential (large lot)
Medium-Density Residential	8.6%	112 - Medium Density Residential (2-8 du/acre) 115 - Mobile Home Park
Grasslands	14.7%	3 - Rangeland - low cover and scrub/brush 22 - Orchards, Groves, Vineyards, Nursery 231 - Cattle Operations 241 – Farmstead 2121 - Improved Pasture 2122 - Unimproved Pasture 2431 - Managed Grasslands - (includes rural golf courses) 18 - Open urban land (golf courses, zoos, cemeteries, fairgrounds - mostly porous surfaces
Urban	9.9%	12 - Commercial and Services - Retail, government, educational, correctional, religous 13 - Industrial - manufacturing, etc. 14 - Transportation, Communication and Utilities 16 - Mixed urban or built up Land 113 High Density Residential (more than 8 du/acre)
Water	0.8%	5 - Water - all but wetlands

Table 3.2. Distribution of major land use classes between subwatersheds in the Moore's Creek watershed. Values shown are acres.

SW#	Forest	Low-Density Residential	Med-Density Residential	Grassland	Urban	Water	Total
1	581.3	629.7	120.0	523.9	269.5	26.1	2150.5
2	1789.6	85.6	0.0	107.8	110.8	79.7	2173.5
3	2605.3	548.4	10.2	348.6	144.0	1.7	3658.1
4	26.1	0.0	0.4	11.0	5.8	0.0	43.3
5	943.5	65.7	40.5	410.2	190.3	5.8	1656.0
6	1462.4	107.4	448.5	352.3	30.8	27.8	2429.2
7	3002.7	571.7	15.5	662.2	2.9	8.9	4264.0
8	943.1	76.1	7.7	426.5	11.2	7.8	1472.4
9	358.0	38.7	106.7	130.6	189.3	3.4	826.6
10	498.2	40.6	817.9	271.5	1070.5	14.9	2713.7
11	368.6	31.2	345.7	57.0	189.1	4.4	996.1
Total	12578.9	2195.3	1913.0	3301.6	2214.1	180.6	22383.4

Chapter 4: Fecal Coliform Source Assessment and Loading

4.0 Introduction

Information from a wide variety of sources was utilized to develop the fecal coliform assessment for Moore's Creek. Information sources included the Virginia Department of Environmental Quality (VADEQ), the Virginia Department of Conservation and Recreation (VADCR), the Virginia Cooperative Extension (VCE), the Farm Bureau, the Virginia Department of Game and Inland Fisheries (VADGIF), the Thomas Jefferson Planning District Commission (TJPDC), previous fecal coliform TMDL studies in Virginia, watershed walks, public participation, and professional judgement. In addition, a bacteria source tracking study was completed for the Moore's Creek watershed. In the following sections, the bacteria source tracking study will first be described, followed by detailed descriptions of the loads from each potential source of fecal coliform bacteria in Moore's Creek.

4.1 Bacteria Source Tracking Study

In support of this TMDL, a bacteria source tracking (BST) study was completed during 2000 and 2001 for the TJPDC. Complete details of the BST study can be found in Wiggins (2001b). An antibiotic resistance analysis (ARA) was used to assess the relative importance of different sources of fecal coliform bacteria in Moore's Creek. There are seven basic steps in the ARA. Each step is briefly described below.

a) Collect fecal samples from animals within the watershed.
   For horse, cow, goat, dog, and goose, fecal samples were collected from at least three different individuals in the Moore's Creek watershed. Samples taken from the influent to the Rivanna Water and Sewer Authority (RSWA) advanced wastewater treatment plant were used to characterize the human source. In addition, water samples from the Ragged Mountain Reservoir were characterized to represent the background "wild" response, since the reservoir has little human impact.
b) Isolate and culture bacteria from these samples.

Enterococci bacteria from the fecal samples were cultured on agar in petri dishes. For each "known" source, 12-24 isolated colonies were selected for antibiotic testing.

c) Expose the cultures to various concentrations of sixteen antibiotics to determine the "known" responses.

   Using different antibiotics and different concentrations, a total of 51 different treatments were used. After 48 hours of incubation, the growth of each isolate on each treatment was recorded to create a library of known responses.

d) On multiple days, collect water samples for analysis from various sites in Moore's Creek.

   Water samples were collected at 9 different stream sites in the Moore's Creek watershed on each of 8 dates over a 10-month period. Samples were collected on both dry days and during or immediately after rain events.

e) Isolate and culture bacteria from these water samples

   Step (b) was repeated for the water samples, except that 48 isolates were selected for each water sample.

f) Expose the cultures from the water samples to the antibiotics

   Step c repeated for cultures from water samples.

g) Compare the response of the water sample cultures to that of the "known" responses to classify the source of the bacteria.

   The DISCRIM procedure from the SAS statistical program was used to classify unknown samples based on comparisons with the known library.

The major conclusions of the BST are:

a) Based on an animal-or-human comparison, the watershed is dominated by animal sources with sites ranging from 68% to 95% animal.
b) Based on a human-or-dog-or-livestock-or-wildlife comparison, the wildlife source predominates, ranging from 35% to 72% wildlife sources. Livestock are the next largest source, ranging from 30% to 12%. Dogs (4% to 24%) and humans (2% to 17%) are lower, but typically above the minimum detection levels.
c) The detection of dogs was not elevated at Azalea Park, a popular "dog park".
d) The percentage of wildlife sources is the greatest in the summer and fall.

4.2 Point Sources

There are two point sources operating in the Moore's Creek watershed with current Virginia Pollution Discharge Elimination System (VPDES) permits for fecal coliform bacteria. The Moore's Creek Advanced Wastewater Treatment plant (MCWWTP, VA0025518), operated by the Rivanna Water and Sewer Authority (RWSA), and the Southwood Mobile Home Park (VA0029955) discharge into streams in the watershed (Figure 4.1). The RWSA also has had a permit for fecal coliform bacteria for its Observatory Hill treatment plant. However, this facility has been modified to discharge directly into the sanitary sewer system, thus there are no plans to seek a permit for this facility to discharge fecal coliform bacteria to surface waters.

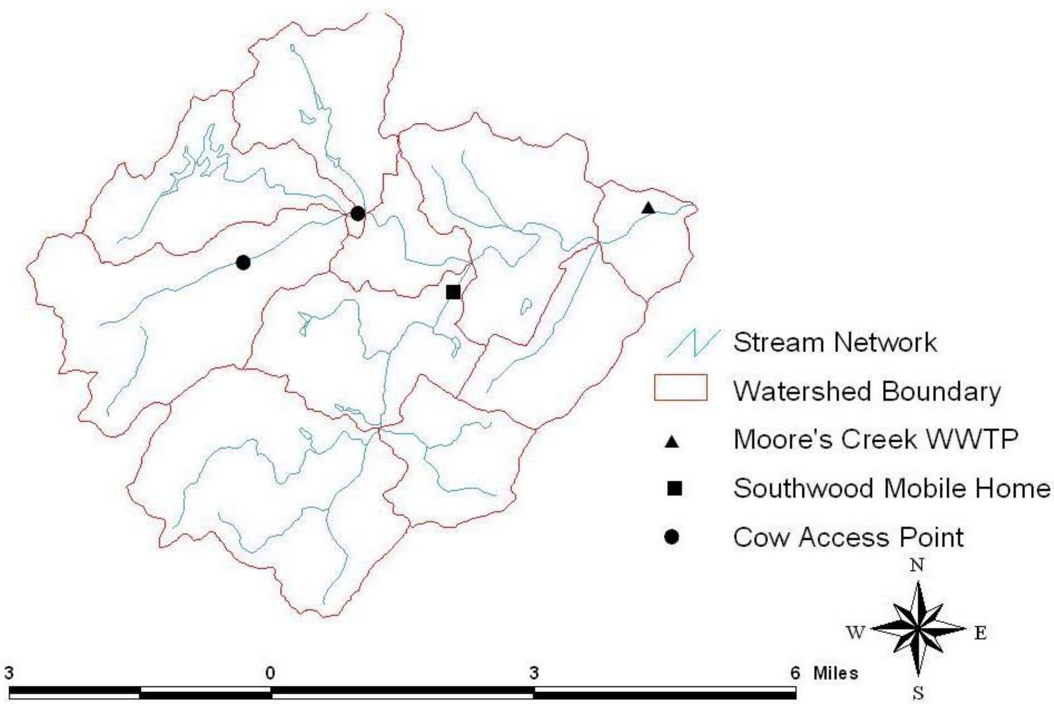

Figure 4.1 Source locations in the Moore's Creek watershed.

The MCWWTP serves the greater Charlottesville area. The MCWWTP is a highly regulated and sophisticated facility, operating an activated sludge system with denitrification. The MCWWTP discharges approximately 10.6 million gallons per day (MGD) or 16.4 cubic feet per second (cfs) into Moore's Creek. The discharge point is 0.6 miles above the Moore's Creek's confluence with the Rivanna River. The volume of outflow from the MCWWTP is approximately 50% of the average flow in Moore's Creek

(32.5 cfs) just upstream of the outflow. However, at times the dominant flow below the MCWWTP will be plant effluent, since during periods of low flow, instream flows may go as low as a few cubic feet per second. In 2001, the average fecal coliform concentration of the effluent from the MCWWTP was 17 cfu/100 ml. Thus, the facility is expected to act as a source of dilution to the stream. Furthermore, the monitoring data from the VADEQ and the RWSA, described in Chapter 2, is taken from a site shortly upstream of the MCWWTP discharge point. Thus, the MCWWTP is not suspected as a significant contributor to the fecal coliform impairment in Moore’s Creek. The MCWWTP has a maximum permitted effluent concentration of 200 cfu/100ml and a design flow of 15 MGD.

The Southwood Mobile Home Park operates a package plant to treat sewage from approximately half the homes in the park, or 180 residences. Septic systems serve the remainder of the homes. The Southwood Mobile Home Park also has a maximum permitted fecal coliform concentration of 200 cfu/100 ml and an expected flow rate of 39,000 gallons per day. On a visit to the park in February 2002, poorly treated waste was observed around the plant outfall, although a grab sample from the effluent had a fecal coliform concentration of 51 cfu/100 ml. Furthermore, the effluent pipe has failed so that the outflow seeps through the bank of Biscuit Run. The accumulation of material and algal growth in the area of the outflow suggest that poor functioning of the treatment plant may not be a rare event, however, there is no record of common permit violations at this facility. The VADEQ water quality monitoring staff is currently investigating the solids in the receiving stream near the outfall of Southwood. The VADEQ will manage this problem through compliance assistance or enforcement.

4.3 Overview of Nonpoint Sources

Nonpoint source pollution comes from spatially distributed sources within a watershed. Sources of nonpoint source loads of fecal coliform bacteria in Moore’s Creek can be grouped into four basic categories: wildlife, livestock, human, and pets. Wildlife includes animals living in and around the waterways. Cattle, horses, and goats contribute to the livestock load. Human loads come from septic systems, straight pipes, and leakage from sanitary sewers. Pet loads are primarily contributed from dogs and cats. Loads from each of these classes are described in the following sections.

4.4 Wildlife

No comprehensive wildlife inventory is available for the Moore's Creek watershed. Significant wildlife species have been identified based on the BST, previous regional coliform TMDL's (Virginia Department of Environmental Quality, 2002), and discussions with representatives of the VADGIF. The five species that have been identified as the major contributors to the wildlife fecal coliform load in the Moore's Creek watershed are deer, geese, raccoon, muskrat, and beaver. The fecal coliform load for other wildlife species that are present in the watershed, such as skunk and opossum, will be addressed by using a load adjustment for 'unidentified' wildlife, as described at the end of Section 4.4.2. To estimate the fecal coliform loads from each significant wildlife species, one must determine the numbers of individuals within the watershed, the seasonal and spatial distribution of individuals, and the fecal coliform production rates per individual. Wildlife densities, habitats, and monthly variability have been based upon information from the VADGIF, the Virginia Trapper's Association, other regional coliform TMDL's, and published reports. In all cases, we have given preference to information specific to the Moore's Creek area, when available.

4.4.1 Major Wildlife Populations and Distributions

<u>Deer</u> – Deer population density and distribution information was based on discussions with Matt Knox, Deer Program Leader with the VADGIF (2001c). Information is specific to Albemarle County. The highest deer densities (45 individuals per square mile) are found in suburban areas due to restrictions on hunting, lack of natural predators, and human intervention. The forest deer population density is lower at 32 individuals per square mile. In both cases, population densities are assumed constant throughout the year, since significant springtime increases in coliform production levels are typically not observed because deer will eat the feces of their offspring. Residential deer densities are applied to low and medium density residential areas, while the forest deer densities are applied to forest and grasslands.

Geese - According to Gary Costanzo of the VADGIF waterfowl division (VADGIF 2001a), the Canada Goose population across the Piedmont region of Virginia remains fairly constant throughout the year. The estimated density (5.52 individuals/sq. mile) is the average goose density across the Piedmont. Thus the total number of geese in the watershed (193) can be found by multiplying the density by the area of the watershed (34.92 sq. miles). However, geese tend to concentrate around larger ponds and near open fields. Thus, these geese will be distributed between subwatersheds based on the relative areas of suitable habitat. Geese habitat includes all open water bodies, all grasslands, all areas within 100 meters of open water bodies, and all area within 20 meters of stream.

Raccoons – The average density (45 individuals per square mile of habitat) was supplied by Randy Farrar of the VADGIF's wildlife division (2001b) and confirmed by Edgar Crebbs of the Virginia Trapper's Association (2001). Seasonal variability, as shown in Table 4.1, was based on the estimates of these experts and on reported litter sizes and seasonality (Connecticut Department of Environmental Protection 1998; E. Dale Joyner Nature Preserve). Raccoon habitat is assumed to be all areas, excluding pastures, within 400 meters of permanent streams (Yagow 2001), ponds, and lakes.

Beaver – Average beaver numbers (4.8 individuals per stream mile and 3.9 per lake shore mile) were supplied by Randy Farrar of the VADGIF's wildlife division (2001b) and confirmed by Edgar Crebbs of the Virginia Trapper's Association (2001). Seasonal variability, as shown in Table 4.1, was based on the estimates of these experts and on reported litter sizes and seasonality (Missouri Department of Conservation, 1997; New Hampshire Cooperative Extension).

Muskrat – Following the Mountain Run TMDL (Yagow 2001), an average muskrat density of 5 individuals per acre of habitat was assumed. Seasonal variability, as shown in Table 4.1, was based on reported litter sizes and seasonality (National Trappers Association, Muskrat, Connecticut Department of Environmental Protection 1998). Muskrat habitat is all areas, excluding urban areas, within 10 meters of perennial streams (Yagow 2001), ponds, and lakes.

Table 4.1. Monthly densities of riparian species (raccoon, beaver and muskrat) in the Moore's Creek watershed.

	Raccoon	Beaver		Muskrat
	Per square mile of habitat	Per stream mile	Per lake mile	Per acre of habitat
Jan	40	3	2.4	2
Feb	40	3	2.4	2
Mar	40	3	2.4	5
Apr	60	10	8.0	5
May	60	10	8.0	9
June	45	4.8	3.9	10
July	45	4.8	3.9	10
Aug	40	4.8	3.9	5
Sept	40	4.8	3.9	5
Oct	40	3	2.4	5
Nov	40	3	2.4	2
Dec	40	3	2.4	2

Figure 3.2 shows the subwatersheds of the Moore's Creek watershed. Based on the habitat information above, the distribution of suitable habitat for each species is shown in Tables 4.2 and 4.3. Combining the habitat and density information, wildlife population per subwatershed by month can be found. Table 4.4 shows the average number of wildlife per subwatershed. The derivation of these values, including the monthly numbers of wildlife can be found in Appendix A. Note that the overall density of deer within the Moore's Creek watershed is 31 individuals per square mile, which is also the average deer density reported for the Piedmont as a whole (Halls 1984).

Table 4.2. Acres of habitat by subwatershed for deer, geese, raccoon and muskrat (1 sq. mile = 640 acres).

SW#	Residential Deer	Forest Deer	Geese	Raccoon	Muskrat
1	749.7	1105.2	667.9	620.0	29.5
2	85.6	1897.4	441.9	1384.4	58.5
3	558.5	2953.9	426.1	1338.0	34.1
4	0.4	37.2	12.9	32.3	2.1
5	106.2	1353.7	483.3	512.4	14.1
6	555.9	1814.7	547.9	1352.5	59.0
7	587.2	3664.9	850.2	2052.2	74.8
8	83.8	1369.6	511.3	540.9	24.5
9	145.4	488.6	187.6	342.5	8.4
10	858.6	769.7	415.3	1481.2	43.0
11	377.0	425.6	128.5	533.3	14.8

Table 4.3. Suitable stream and lakeshore miles and corresponding habitat area for beaver by subwatershed.

Subwatershed	Stream miles	Lakeshore miles
1	2.0	1.9
2	3.1	4.4
3	4.8	0.0
4	0.3	0.0
5	1.4	0.0
6	5.2	2.2
7	8.9	0.4
8	3.1	0.0
9	1.4	0.0
10	5.5	0.5
11	2.0	0.0

Table 4.4. Average number of wildlife by subwatershed.

Sub-watershed	Deer	Geese	Raccoon	Muskrat	Beaver
1	108	28	43	152	17
2	101	18	96	302	31
3	187	18	92	176	23
4	2	1	2	11	1
5	75	20	35	73	7
6	130	23	93	305	33
7	225	35	142	387	44
8	74	21	37	127	15
9	35	8	24	43	7
10	99	17	102	222	28
11	48	5	37	76	9
Total	1083	193	703	1874	215
Overall Density = Total/34.9 sq. miles	31.0	5.5	20.1	53.7	6.2

4.4.2 Wildlife Fecal Coliform Load

In general, fecal coliform production rates are calculated by multiplying the expected waste production rate per individual (g/day) by the expected fecal coliform concentration of the waste (cfu/g). Both the waste generation rate and the coliform concentrations can be expected to vary from individual to individual, depending on size, diet and health. In addition, accurate determination of the fecal coliform concentration of waste is notoriously difficult given the extremely high concentrations typically found. Differences in handling of the waste samples, especially the age of the samples, may also affect bacterial counts. Estimated bacterial concentrations from multiple individuals within the same population may vary by 100,000 times or more (Yagow 2001). In this study, neither the waste production rates nor the fecal concentrations of the waste were measured directly. During calibration of the fecal coliform water quality model, the most reasonable values of wildlife fecal coliform production rates for the Moore's Creek watershed (Table 4.5) were selected from values previously reported (Appendix B), with deference to studies of bacteria in waste in Virginia. The raccoon and muskrat rates were calculated using the geometric average of fecal coliform concentrations reported for their species in other TMDLs (Appendix B). Appendix B provides a summary of studies of fecal coliform production rates. Combining Tables 4.4 and 4.5, the annual average daily coliform loads by wildlife species can be found (Table 4.6). Corresponding information on a monthly basis is shown in Appendix A.

Table 4.5. Coliform production rates for major wildlife species in the Moore's Creek watershed.

Species	Daily Fecal Coliform Production Rate(10^6/head)	Citation
Deer	7720.0	Yagow 2001; Wiggins 2001a
Geese	1710.0	MapTech, Inc. 2001, Wiggins 2001a
Raccoon	814.4	MapTech 2001;Yagow 2001
Beaver	0.2	Yagow 2001, MapTech, Inc. 2001
Muskrat	54.5	Yagow 2001; MapTech 2001

Table 4.6. The annual average wildlife daily coliform loads (10^{10} cfu/day) by subwatershed.

Sub-watershed	Deer	Geese	Raccoon	Muskrat	Beaver
1	83.4	4.7	3.5	0.8	0.0003
2	77.9	3.1	7.8	1.6	0.0006
3	144.3	3.0	7.5	1.0	0.0005
4	1.5	0.1	0.2	0.1	0.0000
5	58.0	3.4	2.9	0.4	0.0001
6	100.2	3.9	7.6	1.7	0.0007
7	173.3	6.0	11.5	2.1	0.0009
8	57.4	3.6	3.0	0.7	0.0003
9	26.8	1.3	1.9	0.2	0.0001
10	76.3	2.9	8.3	1.2	0.0006
11	36.9	0.9	3.0	0.4	0.0002

Some of the load in Table 4.6 is deposited on the land where it may be washed into streams during storm events, and some will be a directly deposited into the stream. To estimate the portion of the load as direct contribution to the stream, first the percentage time spent in the stream or on the banks of the stream was estimated, as shown in Table 4.7. For muskrats, the percentage time in and around the stream is within the range of values used in other fecal coliform TMDLs (Appendix B). Furthermore, it is assumed that only 5% of the fecal coliform load produced while an animal is in and around the stream will actually be deposited directly in the waterway (MapTech, Inc. 2001). Therefore, for each major wildlife species, the direct load to stream is the total load (from Table 4.6), multiplied by the percentage time in and around the stream (Table 4.7), multiplied by 5%. The remainder of the load is the load to the land. The annual average daily land and direct stream load for each major species is shown in Table 4.8 and 4.9. Note that the units of the two tables differ by two orders of magnitude.

Table 4.7. Distribution of wildlife relative to vicinity of stream.

Species	Percentage time upland	Percentage in and around stream	Citation
Deer	99	1	Virginia Tech (2000a)
Geese	75	25	Virginia Tech (2000c)
Raccoon	95	5	MapTech, Inc. (2001)
Beaver	0	100	MapTech, Inc. (2001)
Muskrat	55	45	

Table 4.8. The average wildlife daily coliform loads to land (10^{10} cfu/day).

	Deer (A)	Geese (B)	Raccoon (C)	Beaver (D)	Muskrat (E)	Total Wildlife
SW#	99.95% of load	98.75% of load	99.75% of load	0% of load	97.75% of load	1.3*(A+B+C+D+E)
1	83.4	4.6	3.5	0.00	0.8	120.0
2	77.9	3.1	7.8	0.00	1.6	117.5
3	144.2	3.0	7.5	0.00	1.0	202.4
4	1.5	0.1	0.2	0.00	0.1	2.5
5	58.0	3.4	2.9	0.00	0.4	84.1
6	100.1	3.9	7.7	0.00	1.7	147.4
7	173.2	5.9	11.5	0.00	2.1	250.5
8	57.4	3.6	3.0	0.00	0.7	84.1
9	26.8	1.3	1.9	0.00	0.2	39.3
10	76.3	2.9	8.3	0.00	1.2	115.3
11	36.9	0.9	3.0	0.00	0.4	53.6

To determine the total wildlife loads, unidentified wildlife species must be addressed. Other wildlife, such as skunk, opossum, rodents, and ducks, are also common in the watershed, but population estimates and/or fecal coliform production rates are generally unknown for other wildlife species. Therefore, multipliers will be applied to the total fecal coliform load from the five identified species (deer, geese, raccoon, muskrat, and beaver) to account for the fecal coliform load from all unidentified wildlife species (MapTech, Inc., 2000). An additional 10% of the instream load (MapTech, Inc., 2000) and an additional 30% of the land load from the identified wildlife species will be added to represent the load from unidentified wildlife. A higher adjustment is used for the land load due to the generally higher number of large terrestrial species that were not specifically modeled. Tables 4.8 and 4.9 also show the estimated total fecal coliform loads from wildlife.

Table 4.9. The average wildlife daily coliform loads directly to stream (10^8 cfu/day)

Sub-watershed	Deer (A) .05% of load	Geese (B) 1.25 % of load	Raccoon (C) 0.25% of load	Beaver (D) 100% of load	Muskrat (E) 2.25% of load	Total Wildlife 1.1*(A+B+C+D+E)
1	4.17	5.90	0.87	0.03	1.86	14.12
2	3.89	3.90	1.95	0.06	3.70	14.86
3	7.22	3.76	1.88	0.05	2.16	16.57
4	0.07	0.11	0.05	0.00	0.13	0.40
5	2.90	4.27	0.72	0.01	0.89	9.68
6	5.01	4.84	1.90	0.07	3.73	17.11
7	8.67	7.51	2.88	0.09	4.74	26.27
8	2.87	4.52	0.76	0.03	1.55	10.70
9	1.34	1.66	0.48	0.01	0.53	4.42
10	3.82	3.67	2.08	0.06	2.72	13.58
11	1.84	1.13	0.75	0.02	0.94	5.15

4.5 Livestock

The Moore's Creek watershed is not a region of intensive agriculture. This is supported by the current land use classification by the TJPDC in which no land was identified as cropland. Cattle, horses, and goats have been identified as the only significant livestock species. The fecal coliform loads from these species will be described below. As with wildlife, to estimate the fecal coliform loads from livestock one must first determine the numbers of individuals within the watershed, the seasonal and spatial distribution of individuals, and the fecal coliform production rates per individual.

4.5.1 Livestock Populations and Distributions

The most recent livestock census (VADCR) for the watershed is based on the averaged livestock values from 1987 and 1992 agricultural statistics for Albemarle County. The county numbers were disaggregated to Hydrologic Unit by local personnel from the Soil and Water Conservation District, Natural Resource Conservation Service (NRCS), Farm Service Agency (FSA), and Virginia Cooperative Extension (VCE). According to this database, there are 1650 beef cows and 100 horses in the Moore's Creek watershed. However, during the last decade the Moore's Creek watershed has been developing, resulting in significant loss of operating farms. In support of this TMDL, the Albemarle County Farm Bureau spearheaded a count of large livestock within the watershed. This 2002 count found just 210 cattle or horses within the watershed (exclusive of the stockyard near the Moore's Creek wastewater treatment plant) (Scharer 2002). For the purposes of this TMDL, it is assumed that 400 beef cattle and 100 horses are representative of the livestock populations in the Moore's Creek watershed during the 1996-2001 period over which significant fecal coliform observations are available.

Goats have also been identified as a potentially important contributor to the livestock load in Moore's Creek watershed (Wiggins 2001b). Although discussions have taken place with local VCE, NRCS, and farm association personnel, no quantitative data on goat populations could be found for the Moore's Creek watershed. However, goats have been observed in the watershed, including semi-feral goats near the stockyard above the State water quality sampling point. Furthermore, the BST detected goats at all sampling points in its study (Wiggins 2001b). Based on discussions with local agricultural experts and the public feedback, a population of 80 goats is assumed for the watershed.

The consolidated land use category of grassland shown in Table 3.1 includes a variety of land use classes. These grassland types would have similar hydrological properties and similar wildlife populations. However, livestock will not be found on all of these grasslands. To appropriately determine the livestock distribution and loads, the consolidated land use category of grassland will be divided into grasslands that are not used by livestock and pasture, which is suitable for livestock. Pasture represents 69% of the larger consolidated grassland category. Pasture is composed of the land uses (with corresponding numerical codes): rangeland (3), cattle operations (231), farmstead (241), improved pastures (2121), and unimproved pastures (2122). Non-livestock grassland is composed of managed grasslands (2431), open urban lands, such as golf courses (18), and orchards and vineyards (22). All beef cows, all horses, and 60 goats are distributed among subwatersheds proportionally to the distribution of pasture acreage between subwatersheds. Twenty goats were added to subwatershed 9 to represent the higher density of goats in and around the stockyard above the treatment plant. Table 4.10 shows the number of beef cow, horse, and goat in each subwatershed.

Table 4.10 Distribution of Livestock

SW#	Pasture Acreage (A)	% of total pasture in subwatershed (B)	Beef Cow 400*B	Horse 100*B	Goat 60*B
1	152.8	6.7%	27	7	4
2	107.9	4.7%	19	5	3
3	309.4	13.6%	54	14	8
4	11.0	0.5%	2	0	0
5	242.8	10.6%	43	11	6
6	352.1	15.4%	62	15	9
7	496.8	21.8%	87	22	13
8	398.8	17.5%	70	17	10
9	66.6	2.9%	12	3	23 [a]
10	111.6	4.9%	19	5	3
11	32.3	1.4%	5	1	1
Total	2282.2	100.0%	400	100	80

[a] 60*B + 20

4.5.2 Fecal Coliform Load from Livestock

For each livestock species, the daily fecal coliform loads must be estimated and then distributed appropriately. The assumed daily fecal coliform production rates for the three livestock species are given in Table 4.11. The most appropriate production rates for the Moore's Creek watershed were selected within the range of reported values (Appendix B) during calibration of the water quality model. When Tables 4.10 and 4.11 are combined, the total fecal coliform load, by subwatershed, from livestock can be determined (Table 4.12).

Table 4.11. Fecal coliform production rates for livestock.

Livestock	Fecal coliform production (10^6 cfu/animal/day)	Citation
Beef cow	20739	Yagow (2001)
Horse	420	ASAE 1998
Goat	28490	ASAE 1998, MapTech, Inc. 2001

Table 4.12. Beef cattle, horse and goat daily coliform loads (10^{10}cfu/day).

Subwatershed	Cattle	Horse	Goat
1	56.0	0.3	11.4
2	39.4	0.2	8.5
3	112.0	0.6	22.8
4	4.1	0.0	0.0
5	89.2	0.5	17.1
6	128.6	0.6	25.6
7	180.4	0.9	37.0
8	145.2	0.7	28.5
9	24.9	0.1	65.5
10	39.4	0.2	8.5
11	10.4	0.0	2.8

Where these livestock spend the day and how they are managed affects when and where their wastes will be deposited in the watershed, and thus impacts the likelihood of the livestock waste reaching the streams. Horses and goats are assumed to be in pasture year round, thus all their loads shown in Table 4.12 will be deposited on land (Map Tech, Inc., 2000). Cattle may be in pasture, in confinement, or in and around the stream. While dairy cattle often spend a significant period of time each year in confinement and require manure storage facilities, in beef operations confinement and manure management approaches are less common. For instance, in the Dry River Fecal Coliform TMDL (Virginia Tech 2000a), it was assumed that 10% of the annual beef cattle manure load would be collected during confinement in the winter, stored, and spread on pasture and cropland at a later date. The Moore's Creek area is an area with less intensive agriculture than in the Dry River watershed, and manure storage operations are expected to be less common. Furthermore, there is no land designated as cropland within the Moore's Creek watershed, thus any stored manure would ultimately be applied back to pasture. Therefore, since it is a relatively small percentage of the beef cattle load that may be handled with storage and pasture spreading, for simplicity, it will be assumed that beef cattle spend all their time either in pasture, or, for those cattle with stream access, in or around the stream. This approach was also taken in the Maggodee Creek Fecal Coliform TMDL (MapTech 2001). The average time that cattle, with stream access, spend in or around the stream is shown in Table 4.13.

Table 4.13. Average time beef cattle with stream access spend in different areas each day (Virginia Tech 2000a).

Month	Time on Pasture Hour/Day	Time near stream Hour/Day
January	23.50	0.50
February	23.50	0.50
March	23.25	0.75
April	23.00	1.00
May	22.50	1.50
June	20.50	3.50
July	20.50	3.50
August	20.50	3.50
September	22.50	1.50
October	23.00	1.00
November	23.25	0.75
December	23.50	0.50

For cattle to have stream access, they must both be in a pasture area contiguous to the stream and fencing must be insufficient to keep cattle out of the stream. In a 1994 section 319 project, the watershed was surveyed for stream access points (Hirschman 2002). Few were found at that time, and some fencing has been added due to that project. Two potential remaining access areas, one in Subwatershed 3 and one in subwatershed 4, have been identified (see Figure 4.1). Table 4.14 indicates the percentage of pasture in these subwatersheds that is contiguous to the stream. The number of cattle with stream access was determined by multiplying the number of cattle in the subwatershed times the percentage of pasture contiguous to the stream. For those cattle in the stream access area, it is assumed that 30% of the manure produced while in the access area is deposited directly in the stream (Virginia Tech 2000b).

Table 4.14. Livestock pasture contiguous to stream for subwatersheds with access points.

Subwatershed	Pasture contiguous to streams (acres)	Pasture (acres)	Percentage of pasture contiguous to streams	Cattle with access to stream
3	79.5	309.4	25.7%	14
4	11.0	11.0	100.0%	2

Given the large mass of manure produced per cow, all of the bacterial content of manure deposited directly in the stream will not go into solution immediately and will not be available for transport. Some material will settle and become attached to rocks and sediment on the stream bottom, where if undisturbed the bacteria will die-off. In fact, a study by Kress and Gifford (1984) found that under baseflow conditions, 95% of the fecal coliform from a slurry of livestock manure introduced to a stream disappeared or became unavailable within 50 meters of where it was introduced. Thus, the effective load to the stream from cattle will be 5% of the direct cattle load. This approach was also taken in the TMDL for fecal coliform bacteria for Mountain Run, Culpeper County, Virginia (Yagow 2001).

Using these assumptions and the information in Tables 4.12, 4.13, and 4.14, the effective direct fecal coliform load from cattle to the stream and to pasture, for each subwatershed, by month, can be determined (Table 4.15 and 4.16). The units for these two tables differ by two orders of magnitude.

Table 4.15 Effective beef cattle daily coliform loads directly to stream (10^8 cfu/day)

SW #	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.9	0.9	1.4	1.8	2.7	6.4	6.4	6.4	2.7	1.8	1.4	0.9
4	0.1	0.1	0.2	0.3	0.4	0.9	0.9	0.9	0.4	0.3	0.2	0.1
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4.16 Beef cattle daily coliform loads to land (10^{10} cfu/day).

SW#	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	56.0	56.0	56.0	56.0	56.0	56.0	56.0	56.0	56.0	56.0	56.0	56.0
2	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4
3	111.8	111.8	111.7	111.6	111.4	110.7	110.7	110.7	111.4	111.6	111.7	111.8
4	4.1	4.1	4.0	4.0	3.9	3.5	3.5	3.5	3.9	4.0	4.0	4.1
5	89.2	89.2	89.2	89.2	89.2	89.2	89.2	89.2	89.2	89.2	89.2	89.2
6	128.6	128.6	128.6	128.6	128.6	128.6	128.6	128.6	128.6	128.6	128.6	128.6
7	180.4	180.4	180.4	180.4	180.4	180.4	180.4	180.4	180.4	180.4	180.4	180.4
8	145.2	145.2	145.2	145.2	145.2	145.2	145.2	145.2	145.2	145.2	145.2	145.2
9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9
10	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4
11	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4

4.6 Human

Private and public sewage systems may act as nonpoint sources of fecal coliform bacteria. The first step in determining the load of fecal coliform bacteria from humans is determination of the number of homes and residents within the watershed. The total number of homes in the watershed, the number served by sanitary sewers, and the number with septic systems have been estimated (Table 4.17). The estimates were developed using four sources of information: a list of residences within the City of Charlottesville that are not connected to the sewer system, obtained from the City's billing office; the Albemarle County Service Authority's (ACSA) GIS plot of the sewer system; the Albemarle County Planning and Community Development's 2000 GIS planimetric data of building footprints, and input from the ACSA as to neighborhoods near sewer lines, but not currently connected. Eighty percent of the buildings were assumed to be residential homes. The total number of residents in the watershed (24828) was determined from the 2000 U.S. Census data. This corresponds to an average of 2.63 people per home within the watershed, which is consistent with population density estimates for the county.

Table 4.17. Homes and types of sewage systems in Moore's Creek watershed. (NA indicates Not Applicable.)

SW#	Houses total	Houses With Septics	% With Septics	Houses sewer	Pre-1965	1965-1984	1985-present
1	462	300	65	162	158	129	175
2	36	36	100	0	16	10	10
3	140	140	100	0	85	24	31
4	0	0	0	0	0	0	0
5	154	40	26	114	52	30	72
6	900	344	38	556	58	46	796
7	190	190	100	0	64	54	72
8	50	50	100	0	34	14	2
9	500	55	11	445	23	8	469
10	5724	0	0	5724	NA	NA	NA
11	1283	0	0	1283	NA	NA	NA
Total	9439	1352		8087	490	315	1627

4.6.1 Private Sewage Systems

The dominant fecal coliform impact from home septic systems occurs during system failures, during which untreated or poorly treated wastes are discharged from the systems. Wastes may backup into homes or pool at the ground surface. Although a list of reported septic system failures was obtained from the Health Department, significant numbers of failures may go unreported. The following procedure was used to estimate the number and distribution of failing septic systems. Since the likelihood of system failure is related to the age of the septic system, homes were divided into three age categories, pre-1965, 1965-1984, and post-1984 (Table 4.17). Historical home distributions were based on USGS 7.5-min topographic maps that were developed from 1963-1965 aerial photos with photo-revisions from 1972, 1974, 1979 and 1984. Age classes were not determined for subwatersheds 10 and 11, since all homes in these areas are served by sewer lines. It is assumed that the percentage sewered homes has remained constant. Furthermore, it is assumed that septic failure rates in pre-1965, 1965-1984, post-1984 age categories are 40%, 20% and 5% (Virginia Tech 2000b). Applying these assumptions to the number of homes with septic systems (Table 4.17), the average number of failing septic systems, by subwatershed, can be determined (Table 4.18). As was summarized in the Maggodee Creek, Virginia, TMDL (MapTech, Inc., 2001), a wide range of failure rates for septic systems have been assumed in previous Virginia fecal coliform TMDLs. The failure rates assumed in this work are at the high end of the range to err on the side of caution. Furthermore, feedback from community committee suggested that failure rates from the low end of the range would underestimate the human impact in this watershed.

Table 4.18. Number of homes with septic systems, by age, number failing systems and resulting fecal coliform load.

SW#	Pre-1965 (A)	1965-1984 (B)	1985-present (C)	Failing Septic tanks A*0.4 + B*0.2 + C*0.05 (D)	Daily fecal coliform load (10^{10} cfu/day) D*0.513
1	102	84	113	63	32.3
2	16	10	10	9	4.6
3	85	24	31	40	20.5
4	0	0	0	0	0.0
5	14	8	19	8	4.1
6	22	18	304	28	14.4
7	64	54	72	40	20.5
8	34	14	2	17	8.7
9	3	1	52	4	2.1
10	0	0	0	0	0.0
11	0	0	0	0	0.0

The daily fecal coliform load to the land surface from a failing septic tank is determined by multiplying the average occupancy rate (2.63 individuals per home) by the per capita fecal coliform production rate of 1.95 * 10^9 cfu/day (Geldreich 1978). Thus, the fecal coliform load to land from a failing septic tank is 5.13 * 10^9 cfu/day in this watershed. When this value is multiplied by the number of failing systems per subwatershed, the fecal coliform load to the land from failing septic systems is determined (Table 4.18). This fecal coliform load from failing septic tanks is assumed to be deposited on low- and medium-density residential areas, with the load divided proportionally to the density of housing units on each land use.

Although it is not an approved system, a few residences may have direct pipes discharging untreated wastes into the stream. Table 4.19 shows the number of straight pipe systems, assuming that 1.0% of the oldest (Pre-1965) unsewered homes and 0.5% of the other unsewered homes have straight pipes. The fecal coliform load from straight pipe systems is assumed to be directly discharged to the stream (Table 4.19).

Table 4.19. Number of straight pipes and resulting fecal coliform load.

Sub-water-shed	Pre-1965 Septics (A)	Straight pipes A *0.01 (B)	Post-1965 Septics (C)	Straight pipes C *0.005 (D)	Daily fecal coliform load (10^{10}cfu/day) (B+D)*0.513
1	102	1	197	1	1.02
2	16	0	20	0	0.00
3	85	1	55	0	0.51
4	0	0	0	0	0.00
5	14	0	27	0	0.00
6	22	0	322	2	1.02
7	64	1	126	1	1.02
8	34	0	16	0	0.00
9	3	0	53	0	0.00
10	0	0	0	0	0.00
11	0	0	0	0	0.00

4.6.2 Public Sanitary Sewer Systems

The greater Charlottesville area is served by separate sanitary and stormwater sewer systems. Thus, the sanitary sewer system should not be a substantial contributor of coliform bacteria into Moore's Creek. However, there is always the potential for leakage from both sanitary and stormwater sewer systems and episodic pipe failures. The magnitude of human contributions from a sewer system is site-specific, dependent on the age, design, and condition of the sewer systems. For the Moore's Creek watershed, the bacteria source tracking study (Wiggins 2001) found that the percentage of human bacteria detected at the sampling point with the most urbanized drainage was consistent with the human percentage at other points in the watershed. Thus, it is assumed that there would be some load from the sanitary sewage system; 0.5% of the household fecal coliform load from homes served by sanitary sewers was applied as a nonpoint source load to urban areas. The load from the sanitary sewer system is shown in Table 4.20.

Table 4.20 Fecal coliform bacteria load from sanitary sewer system by subwatershed

SW#	Houses Sewer (A)	Daily Fecal Coliform Load (10^{10}cfu/day) (A)*(0.005)*0.513
1	162	0.42
2	0	0
3	0	0
4	0	0
5	114	0.29
6	556	1.14
7	0	0
8	0	0
9	445	1.14
10	5724	14.68
11	1283	3.29

4.7 Pets

Among pets, cats and dogs are the primary potential contributors to the fecal coliform load in the watershed. The assumed fecal coliform production rates for cats and dogs are shown in Table 4.21. Following the American Veterinary Medical Association (AVMA), an average of 0.60 cats and 0.53 dogs per household is assumed (AVMA, 1997). Since the total populations of cats and dogs are similar, but the fecal coliform production rate for dogs is more than 2 million times greater than that of cats, it is clear that compared to dogs, cats are an insignificant contributor to the fecal coliform load and will be dropped from further analysis. Table 4.22 shows the fecal coliform loads, by subwatershed, due to dogs. This fecal coliform load from pets is assumed to be deposited on low- and medium-density residential areas and on urban areas, with the load divided proportionally to the density of housing units on each land type.

Table 4.21. Daily fecal coliform production rates from pets.

Pets	Fecal coliform production (10^6 cfu/animal/day)	Citation
Cat	0.0005	MapTech, Inc. 2001
Dog	1070	Average of MapTech, Inc. 2001 and CH2MHill 2000

Table 4.22. Fecal coliform loads from dogs in the Moore's Creek watershed.

Subwatershed	Houses Total (A)	Number of dogs B=0.534*A	Fecal Coliform Load (10^{10} cfu/ day) 0.107*B
1	462	247	26.4
2	36	19	2.0
3	140	75	8.0
4	0	0	0
5	154	82	8.8
6	900	481	51.5
7	190	101	10.8
8	50	27	2.9
9	500	267	28.6
10	5724	3057	327.1
11	1283	685	73.3
Total	9439	5041	

4.8 Summary of Fecal Coliform Loads

Each land use accumulates fecal coliform bacteria from various sources (Table 4.23), with loads varying by month. The annual total fecal coliform loads for these land uses are shown in Table 4.24. In addition to deposition to the land surface, a variety of sources, including point and nonpoint, contribute fecal coliform loads directly to the stream (Table 4.23). The annual fecal coliform loads deposited directly into the stream are also shown in Table 4.24.

Table 4.25 shows the percentage of annual land and stream loads from each major source. Note that these values do not necessarily represent the impact to the stream. The mass of land load that washes into the stream will be dependent on factors, such as the amount of impervious surfaces. Furthermore, the location of both land and in-stream loads within the watershed will affect how large of an impact they have on the water quality at the sampling site. Unlike direct nonpoint sources, point sources also include additional flows of water that will provide dilution of the load. The model described in Chapter 5 will allow the contributions of fecal coliform (load that actually reaches the stream) to be estimated and assigned to source type.

Table 4.23 Sources of fecal coliform bacteria applied to each land use in the Moore's Creek watershed.

Land use category	Fecal coliform bacteria sources
Forest	Deer, geese, raccoons, muskrats, and unidentified wildlife
Low-Density Residential	Deer, geese, raccoons, muskrats, unidentified wildlife, septic failures and dogs
Medium-Density Residential	Deer, geese, raccoons, muskrats, unidentified wildlife, septic failures and dogs
Grasslands	Deer, geese, raccoons, muskrats, unidentified wildlife, cattle, horses and goats
Urban	Geese, raccoons, and unidentified wildlife, dogs, and sanitary sewer system leakage
Water	Geese, raccoons, muskrats, and unidentified wildlife
Directly to Stream	Deer, geese, raccoons, muskrat, beaver, unidentified wildlife, cattle, straight pipes, and point source loads

Table 4.24. Annual fecal coliform loads in the Moore's Creek watershed.

SW#	Forest	Low Density Residential	Medium-density Residential	Grassland	Urban	Direct NPS	Point Source
	10^{13} cfu/year					10^{11} cfu/year	
1	11.4	26.6	12.7	36.2	3.0	42.6	0
2	37.1	4.4	0.0	19.9	0.8	5.4	0
3	50.4	23.9	1.1	56.9	1.2	25.8	0
4	0.6	0.0	0.0	1.7	0.0	0.3	0
5	18.2	2.6	3.4	47.9	2.3	3.5	0
6	30.1	4.0	35.2	64.3	1.0	43.7	1.1
7	60.4	26.1	1.8	94.2	0.0	47.0	0
8	18.9	4.9	1.6	73.0	0.2	3.9	0
9	7.2	1.6	9.9	35.9	4.4	1.3	25.7
10	10.8	1.9	106.3	23.6	41.7	5.0	0
11	7.7	1.3	31.8	6.1	5.4	1.9	0

Table 4.25. Percentage of fecal coliform load from each major source in the Moore's Creek watershed.

Major Source	On land loads	Instream Loads
Wildlife	41.3%	23.2%
Livestock	36.0%	0.6%
Human	4.4%	76.2%
Pet	18.3%	0.0%

Chapter 5: Model Development and Calibration

5.0 Introduction

The primary purpose of a simulation model in TMDL development is to illustrate the relationship between loads (both point and non-point source) and the ultimate water quality of the stream. Once these relationships have been established, one can explore the impact of alternative management scenarios with the goal of improving water quality. In this work, the Nonpoint Source Model (NPSM), part of the BASINS package (USEPA 1998) is being applied to the simulation of flow and bacteria transport in the Moore's Creek watershed. NPSM simulates the mechanisms of flow and transport and includes an interface to a Geographic Information System (GIS) for input and manipulation of the extensive data required for watershed modeling. The first step in water quality modeling is accurate description of the hydrology of the system. Flow predictions are required to describe the wash-off of nonpoint pollution from land surfaces and the routing and dilution of bacteria once it reaches the stream. Thus, the following sections will first present the development, calibration, and validation of the flow model for the Moore's Creek watershed, followed by a description of the water quality model for fecal coliform bacteria.

5.1 Hydrological Model Formulation

The NPSM is essentially the Hydrologic Simulation Program – FORTRAN (HSPF), which was developed by the U.S. Geological Survey (Bicknell et al. 1997), with a GIS interface. For some steps in the hydrological model development, such as the calibration, the HSPF model was used directly. The NPSM/HSPF model was selected because of its ability to simulate both nonpoint and point source loads, as well as the flow and transport of pollutants in each stream reach. In addition, the model allows for assessment of in-stream water quality response to changes in flow, season, and load (Bicknell et al. 1997). The NPSM/HSPF model has separate submodels for pervious and impervious areas within the watershed due to the significantly different hydrological behavior of these two land types. Additional subroutines describe flow and transport within the stream channels.

5.1.1 Subwatersheds

To account for spatial variability within the watershed, subwatersheds are defined. Eleven subwatersheds were deemed suitable for a watershed of the size of Moore's Creek. These subwatersheds are shown in Figure 3.2. Subwatersheds boundaries were determined by the topography of the region and the stream network. Each subwatershed is represented by a single primary stream segment. Confluences of significant stream branches form natural outflow points for subwatersheds.

5.1.2 Stream Characteristics

Stream channel geometry for Moore's Creek was estimated from measurements of stream geometry at select locations within the watershed and visual inspection. The major stream reaches in the Moore's Creek watershed were modeled as trapezoidal cross-sections. Table 5.1 shows the physical characteristics of the Moore's Creek stream system.

Table 5.1 Characteristics of the major stream reaches in each subwatershed of the Moore's Creek model.

SW#	Length (miles)	Average Depth (ft)	Average Width (ft)	Slope
1	2.51	0.6	18	0.005
2	4.60	0.4	12	0.012
3	3.50	0.5	18	0.008
4	0.29	0.8	25	0.010
5	2.42	0.4	12	0.008
6	2.75	0.8	25	0.003
7	4.35	0.8	12	0.006
8	1.96	0.8	12	0.006
9	0.80	1.5	40	0.00005
10	2.76	1.5	40	0.0001
11	1.95	0.8	25	0.010

5.1.3 Weather Data

Weather data was obtained directly from the Virginia State Climatologist Office in Charlottesville, Virginia. The primary sources of weather information for the model input files were the Charlottesville 2W weather station at Observatory Hill and the Monticello weather station. These stations are on the northern and northeast borders of the watershed, respectively (Figure 5.1). Precipitation information is critical for predictions of flow regions. However, significant spatial variability in rainfall is common, and rain gauges measure the precipitation at a single point. Therefore, to estimate a precipitation rate more representative of the average precipitation over the entire watershed, the observations from these two stations were averaged.

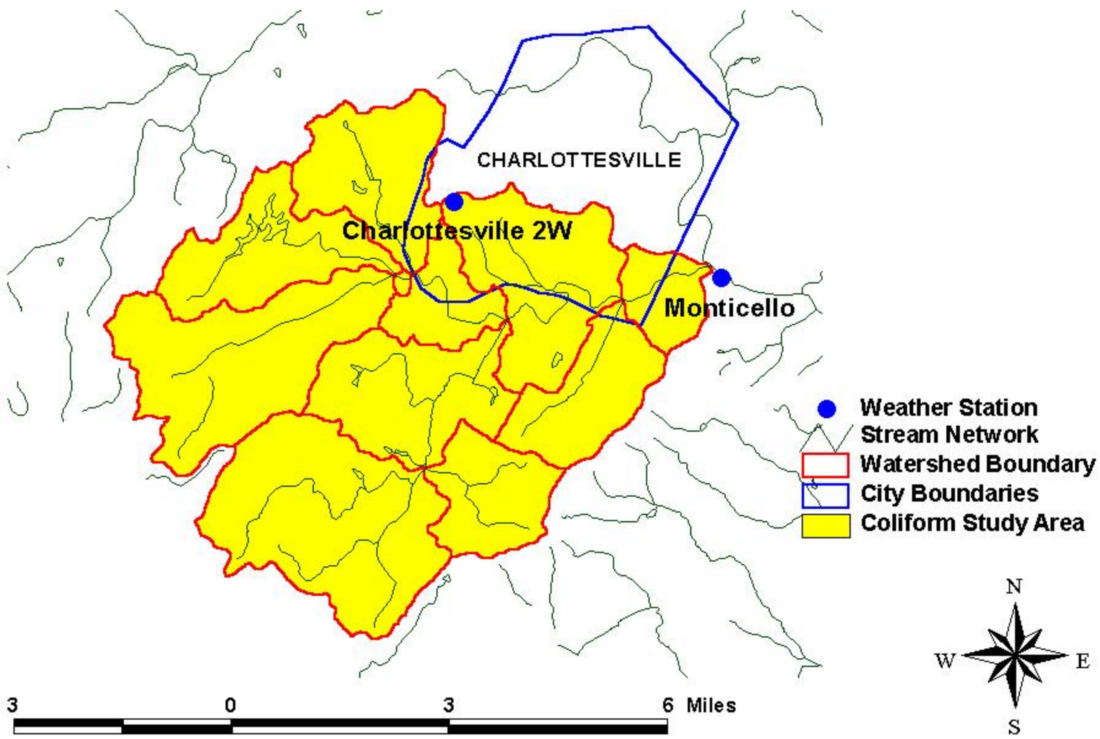

Figure 5.1 Location of weather stations for the Moore's Creek watersheds study.

5.1.4 Land use

The major land use categories and acreage were described in Chapter 3. In addition, to the acreage of each land use, the pervious and impervious area for each land use must be specified. These percentages, shown in Table 5.2, were determined during hydrological calibration by varying percentages within normal ranges.

Table 5.2 Percentage pervious and impervious area by land use.

Major Land Use	% Pervious	% Impervious
Forest	100%	0%
Low-Density Residential	95%	5%
Medium-Density Residential	90%	10%
Grasslands	100%	0%
Urban	75%	25%
Water	100%	0%

5.2 Hydrological Model Calibration and Validation

Model calibration is the process of selecting values of model parameters to accurately represent the hydrologic processes of the watershed. Validation is the testing of the selected values. In general, model predictions are compared to observations of flow to evaluate how well the system is being represented. One set of observations, from one time period, is used for calibration. Another set (or sets) of observations, taken over a different period of time from the calibration set is used for validation. Parameter values are not re-adjusted for validation. Typically, continuous flow observations over a period of five years would be considered minimal for this process. Preferably, a decade or more of flow observations would be used.

5.2.1 Available Flow Data

Unfortunately, no continuously recording stream gauge exists in the Moore's Creek watershed. A peak flow gauge (USGS 02033300) has been operating in the watershed since 1967. However, this gauge only records the magnitude and date of the maximum observed flow each year. This gauge is also in the upper reaches of the watershed with a drainage area of only 3.53 sq. miles. A staff gauge was installed in Moore's Creek at the water quality monitoring site in the summer of 2000. (The staff gauge is located at the site of the Moore's Creek Advanced Wastewater Treatment Plant, shown in Figure 4.1). No recording device was installed; observations of stream height must be made and recorded manually. When observations of stream flow or height from the U.S. Geological Survey, the Rivanna Water and Sewer Authority (RWSA), community stream volunteers, and the University of Virginia are combined, there are 125 individual observations of flow at the sampling site between August 1999 and August 2001, with the majority taken during a single year. This limited data set, due to both the small number of observations and the limited time period, is insufficient for appropriate calibration of a mechanistic hydrological model.

5.2.2 The Equivalent Watershed and Synthetic Data

Two approaches were taken and combined to address hydrological model calibration under extreme data limitations. One approach was the equivalent watershed approach and the second was development of a synthetic flow generator to create a statistically reasonable prediction of flow in Moore's Creek, extending the 125 flow observations. Each of these methods and their integration is described below.

For data-limited watersheds, a paired or equivalent watershed approach can be taken to allow for hydrological model calibration. In the equivalent watershed approach, a second watershed is found that is nearby the data-limited watershed and has similar hydrologic properties to the data-limited watershed. In addition, the second watershed must have a hydrologic record sufficiently long to allow for calibration of a mechanistic watershed model. In the equivalent watershed approach, the analyst can calibrate the mechanistic watershed model (such as NPSM) to the second or equivalent watershed and then use the values of the model parameters determined for the equivalent watershed to model the data-limited watershed. Theoretically, if the watersheds are sufficiently similar, little, if any, adjustment of parameter values should be needed to model the data-limited watershed. The equivalent watershed approach has been successfully used for several fecal coliform TMDLs in Virginia (Virginia Tech 2000b; CH2MHill 2000).

The Buck Mountain Run watershed, also in the Rivanna River drainage basin, was selected as an equivalent watershed (Figure 5.2). The Buck Mountain Run watershed is compared to the Moore's Creek watershed in Table 5.3. The watersheds are of similar size and have similar dominant land uses, although the Moore's Creek watershed (circa 2000) is a bit more developed than the Buck Mountain Run watershed (circa 1993). The Free Union weather stations (Figure 5.2) are the local stations for the Buck Mountain Run watershed. The correlation between the daily precipitation for the Buck Mountain Run and Moore's Creek watersheds is 81.6% for the period from 1990-

1997. The key factor in the equivalent watershed approach is that a continuously recording USGS gauge was operating until 1997 in the Buck Mountain Run watershed.

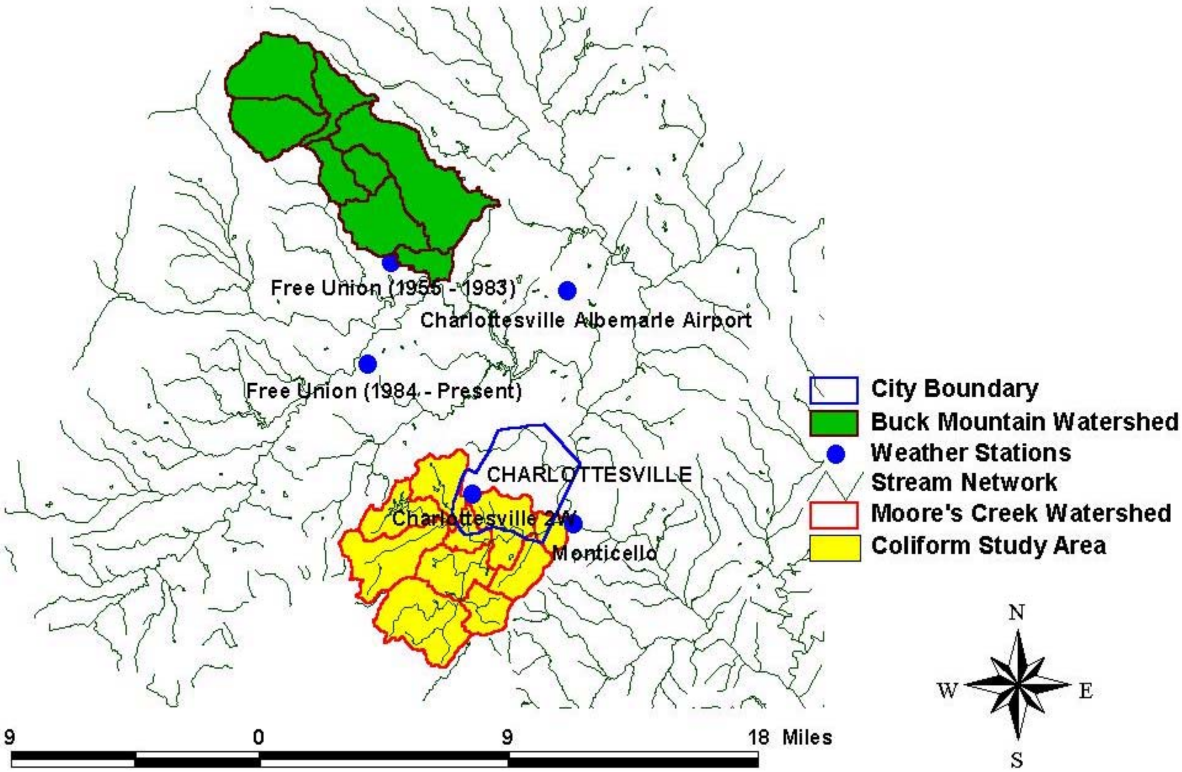

Figure 5.2. Buck Mountain Run and Moore's Creeks watersheds.

Table 5.3. Comparison of watersheds

	Buck Mountain	Moore's Creek
Area	34.6 sq. miles	34.9 sq. miles
Forest	62.1%	56.2%
Pasture	27.8%	14.7%

The Buck Mountain Run gauge provides an excellent flow calibration target for the NPSM model. All the input data sets required for NPSM simulation were obtained and prepared for the Buck Mountain Run system. The land use coverage was from the Thomas Jefferson Planning District Commission from a study completed in 1993. Land uses were grouped into similar groupings as shown in Table 3.1 for Moore's Creek. The Buck Mountain Run watershed was subdivided into eight subwatersheds, as shown in

Figure 5.2. The initial NPSM parameters for Buck Mountain Run were estimated as recommended in USEPA (USEPA 2000) and USGS (Lumb et al. 1994) guidance documents. The input parameters were then manipulated within the reasonable ranges (USEPA 1999b) to achieve a suitable hydrological calibration for the Buck Mountain Run watershed (Figure 5.3). As shown in Table 5.4, the calibration period (10/1992-9/1997) meets all recommended hydrological calibration goals specified by Lumb et al. (1994).

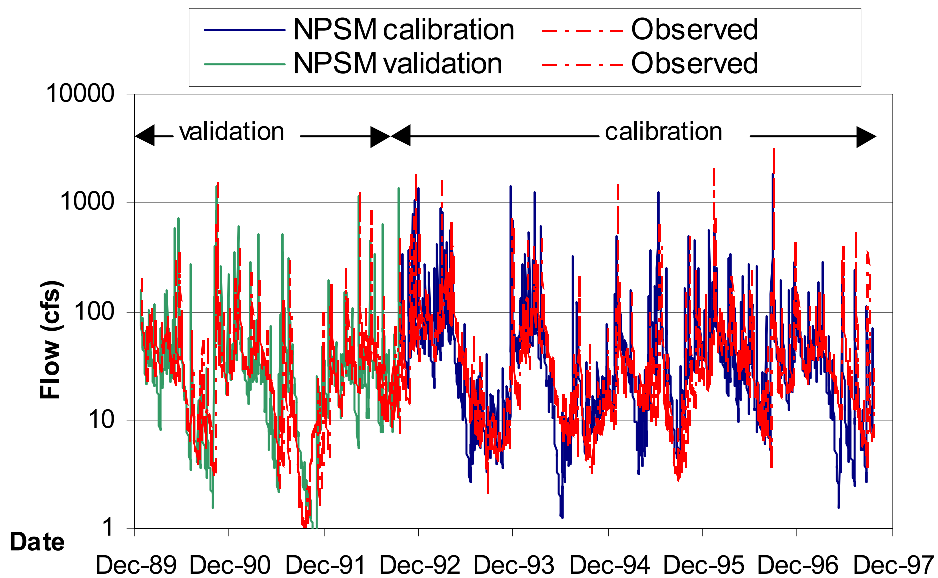

Figure 5.3. Comparison of calibration and validation flows to measured flows in Buck Mountain Run.

For validation, the NPSM model was run for another period (1/1990-9/1992) using the parameter values determined during calibration. The performance during the validation period is reasonable, with the only deviation from the recommended error range occurring for the seasonal volume measurement (Table 5.4), which compares errors in winter versus summer. (No individual storms were specified to measure storm errors during the calibration period.) These validation results imply that the calibration for Buck Mountain Run could be improved slightly. However, as will be seen, the synthetic flow data will allow for improvements in calibration directly to Moore's Creek flows, as described next.

Table 5.4. Calibration and validation measures for the Buck Mountain Run watershed, calculated using the HSPEXP software (Lumb et al. 1994).

	Calibration 10/1/92-9/30/97	Validation 1/1/1990-9/30/92	Recommended Maximum Limits
Total Flow Error	-1.3%	2.0%	+/- 10%
Low Flow Recession	0.00%	-0.01%	+/- 0.01%
Total flow in 50% lowest flows	0.6%	-3.4%	+/- 10%
Total flow in 10% highest flows	-0.3%	14.5%	+/- 15%
Seasonal Volume	4.4%	41.9%	+/- 10%
Storm Volume	9.4%	NA	+/- 15%
Summer Storm Volume	8.1%	NA	+/- 15%

Often in the equivalent watershed approach, the calibrated parameters for the mechanistic model (NPSM) are directly applied to modeling of the data-limited watershed (in this case, Moore's Creek). A visual comparison of the predicted flows to the limited observations is then used to determine whether calibration was sufficient. However, while many possible flow regimes might fit 125 points, there could still be significant variations over a longer flow time period. Thus, in this work, a synthetic flow predictor was used to estimate flows in Moore's Creek. While the synthetic flow generator will not provide the mechanistic description of the watershed needed for the TMDL analysis, a mechanistic watershed model (NPSM) can be calibrated to the synthetic flow series.

To develop and test the synthetic flow predictor, it was first applied to the equivalent watershed, Buck Mountain Run, where sufficient data were available to statistically evaluate performance of the synthetic flow predictor. This work evaluated two types of synthetic flow generators, Maintenance of Variance Extensions (MOVEs) and artificial neural networks (ANNs). The synthetic flow generators do not require spatially distributed input information. Only concurrent time series of inputs that correlate to the flows in the data-limited watershed are needed. These inputs can include flows in neighboring gauges and precipitation information. In general, the requirements of hydrological "equivalence" are greatly relaxed compared to the equivalent watershed approach.

The MOVE method basically corrects linear regression predictions to maintain observed statistical properties of the short time series from the data-limited watershed. Simple linear regression between a longer input series (such as a flow series at a neighboring gauge) and the short series tends to average out variability to minimize the sum of the squared errors. However, while the sum of squared errors is minimized by linear regression, predictions tend to under-estimate high flows and over-estimate lows. As was shown in Chapter 2, the extremes of flow are important hydrological conditions for fecal coliform bacteria in Moore's Creek. MOVE is not a new approach and has a long history of use by hydrologists to extend or fill in flow series. Details on applying the MOVE method can be found in Alley and Burns (1983) and Matalas and Jacobs (1964). The main parameters in the method are the means and standard deviations for the short series and for the corresponding values in the longer series. For flows, the simplest MOVE approach (MOVE1) is calculated as follows:

$$\hat{y}(i) = m(y_i) + \frac{s(y_1)}{s(x_1)}\left(x(i) - m(x_1)\right) \tag{5.1}$$

where $\hat{y}(i)$ and x(i) are the logs of the ith estimated flow and the ith flow in the long series, respectively

$m(y_1)$ and $m(x_1)$ are the means of the logs of the observations in the short series and the corresponding log values in the long series, respectively

$s(y_1)$ and $s(x_1)$ are the standard deviations of the logs of the observations in the short series and the corresponding log values in long series, respectively

Equation 5.1 assumes that flows are log-normally distributed, and thus log-transformed values that approximate a normal distribution are used. The MOVE2 technique allows for corrections if the mean and standard deviation of the short time series are not representative of the desired longer synthetic series (Alley and Burns, 1983). Both MOVE methods are simple and can be readily applied in a spreadsheet.

A form of artificial intelligence, an ANN is a mathematical structure, motivated by biological neural networks, that is capable of simulating a wide range of nonlinear relationships. Maier and Dandy (2000) provide an extensive review of the use of ANN in water resources. In this work, a simple three-layer feed-forward formulation is used. Back-propagation, a first-order gradient search method, is used to optimize the fit.

To test the performance of the synthetic flow generators under data limited conditions, subsets of the USGS observations on Buck Mountain Run were selected as observations for the synthetic generators. The number of observation points was chosen to be similar to the number of observations available on Moore's Creek. For the observations for the MOVE approach, 96 daily flow measurements were randomly chosen from the Buck Mountain Run gauge measurements during the nine-month period between 2/1997 and 10/1997. Thus the MOVE technique approximates both the small number of observations and the short observation period of the Moore's Creek data set. Flows from the USGS gauge (USGS 02031000) on the Mechums River, the most similar nearby gauge location (Figure 5.4), were selected as the long series for the MOVE technique.

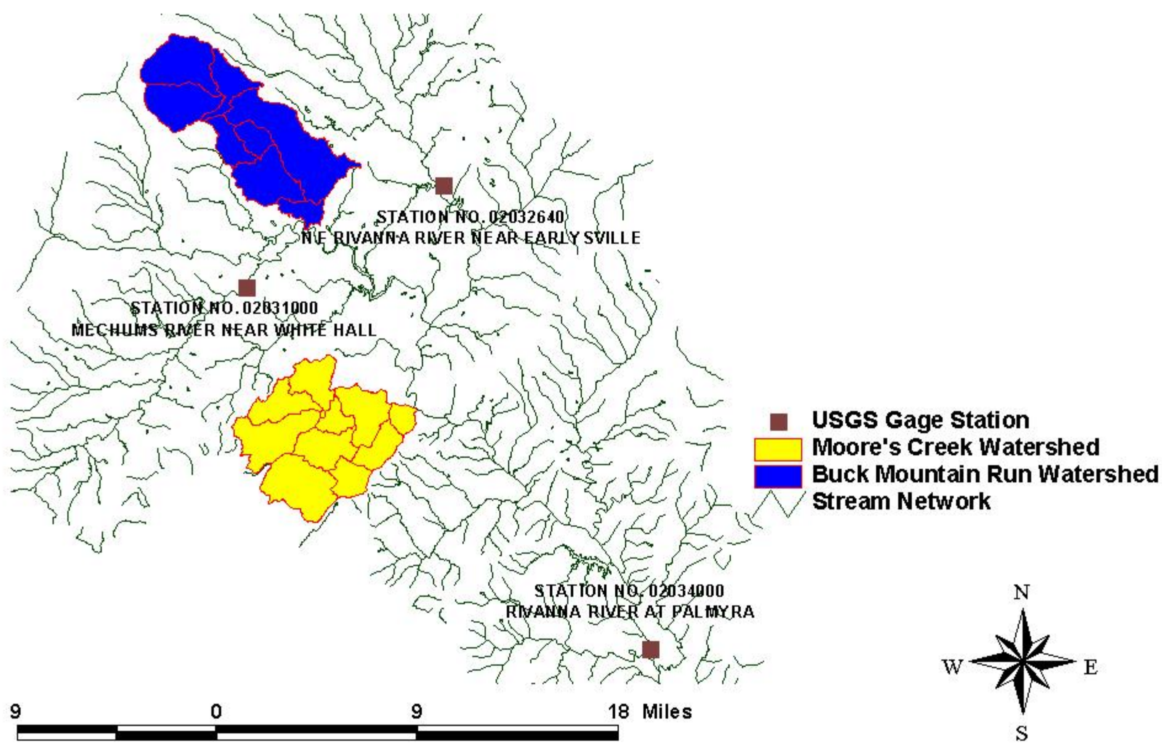

Figure 5.4. Regional gauges used for synthetic flow generators and relationship to Moore's Creek and Buck Mountain Run watersheds.

For the ANN observations, 110 observations from the Buck Mountain Run gauge were randomly chosen during the four-year period between 10/1993-9/1997. Four inputs were used for the ANN. Corresponding flows from the Mechums River, the North Fork of the Rivanna River (USGS 02032640), and the Rivanna River at Palmyra, Virginia (USGS 02034000) (Figure 5.4) were used as three of the inputs into the ANN. The Free Union precipitation was the fourth input into the ANN.

When the MOVE and ANN methods were tested on the Buck Mountain Run watershed, the MOVE technique performed well, although it over-estimated the flows during most summers. The ANN method significantly over-estimated low flows. Thus the ANN model was reformulated so that the measure of fit was the relative root mean squared error, instead of the standard root mean squared error. The relative error formulation essentially seeks to minimize percentage errors; thus a prediction of 6 cfs given an observation of 3 cfs is just as significant an error as a prediction of 600 cfs given an observation of 300 cfs. Using this relative error formulation, the ANN model was the most accurate predictor over most of the flow range, but it significantly under-predicted the highest flows. Therefore, to create a predictor with sufficient accuracy across the entire range of flows, the MOVE technique was combined with the relative error-ANN model. The highest 25% of flows predicted by the ANN model were replaced with the MOVE predictions. The resultant predicted flows are shown in Figure 5.5. When Figures 5.3 and 5.5 are compared, it is readily apparent that the synthetic flow generator is capable of estimating the observed flows more accurately than the NPSM. In fact, the r^2 between the daily synthetic flows and the observed daily flows during the calibration period is 0.90, while the r^2 between the NPSM predictions and the observed flows over the same period is only 0.24. Although the overall pattern and volumes of flows predicted by the NPSM are reasonable, the low daily r^2 value for the NPSM predictions is indicative of differences in daily timing of peaks and lows.

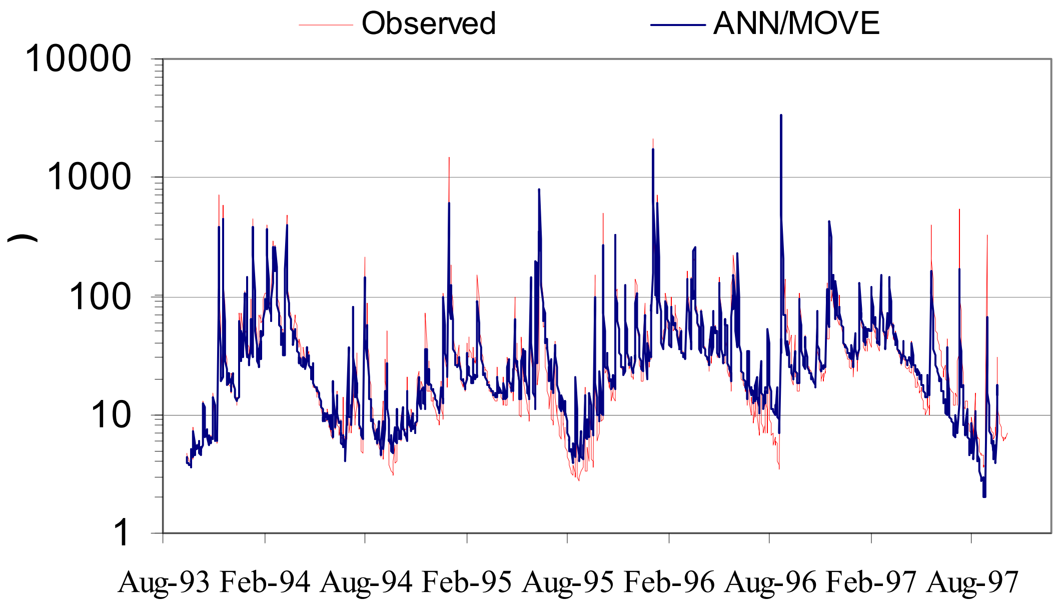

Figure 5.5. Comparison of synthetic flows and observed flows on Buck Mountain Run.

While the synthetic flow predictors have been shown to be capable of accurate predictions across the entire flow range using a limited number of observations, the synthetic flow predictors provide no information about the processes controlling flow. Nor do they demonstrate the relationships between flow and water quality or management alternatives and water quality. Thus, the synthetic flow predictions do not replace the need to calibrate a mechanistic flow model. The MOVE/ANN synthetic flow predictor was applied to the Moore's Creek watershed, using precipitation and the three gauges shown in Figure 5.4 as input. The flows from Buck Mountain Run could not be used as input because no observations were made concurrently with the Moore's Creek observations; that is, the Buck Mountain Run recordings stopped in 1997, while Moore's Creek observations did not begin until 1999. The MOVE2 technique (Alley and Burns 1983) is used for Moore's Creek, since the period over which there are observations is not indicative of the long-term average for the region. Observations were taken over a period of lower than average flows. The MOVE2 technique corrects the averages and standard deviations in Equation 5.1 to account for this difference. The resultant synthetic flow predictions for Moore's Creek, over the period with flow observations are shown in Figure 5.6. As can be seen, the synthetic flow series does an excellent job of reproducing the limited observations of flow on Moore's Creek, including simulating the drought of

1999. The synthetic flows for Moore's Creek will be used as the target for the NPSM model.

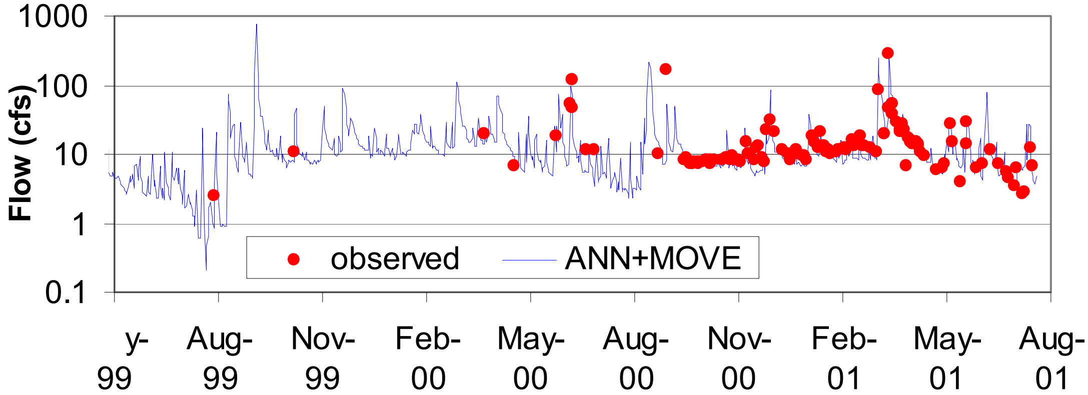

Figure 5.6. Comparison of synthetic and observed flows for Moore's Creek.

5.2.3 Calibration of the Moore's Creek hydrological model

The synthetic flow predictor described in the previous section was first applied to the Moore's Creek watershed to create a calibration target for the NPSM model. The period of calibration was from 10/1/1996 to 8/5/2001 to correspond to the period when most is known about both the flows and water quality of Moore's Creek. The NPSM model parameters determined through the equivalent watershed approach were used as initial values for the Moore's Creek simulations. Using the HSPEXP calibration expert system (Lumb et al. 1994) for guidance, the NPSM parameters were then adjusted to bring the predictions into agreement with the synthetic flows. This additional calibration step can be thought of as fine tuning of the equivalent watershed approach.

Before recalibration began the seasonal errors for Moore's Creek were more dramatic than for the Buck Mountain Run system. Parameters related to impervious areas are important in correcting this error. Given that the Moore's Creek watershed (based on 2000 land use) is more developed than the Buck Mountain Run watershed (based on 1993 land use), it is reasonable that the Moore's Creek watershed would be more sensitive to the description of developed areas. The percentages of impervious areas were adjusted to the values shown in Table 5.2 reduce the seasonal errors.

The calibration of the NPSM model to the synthetic flows for Moore's Creek is shown in Table 5.5 and Figure 5.7. Values of HSPF parameters are shown in Appendix

C. The calibration performs well with only a slight violation of the seasonal error measure. Furthermore, Figure 5.7 shows the NPSM model does a good job reproducing both the synthetic and observed flows. With this calibration, 25.5% of the stream flow is from surface runoff, 22.5% from interflow (near-surface flow through the ground), and 52.0% of the flow is from base flow (or ground water).

Table 5.5. Calibration measures for the Moore's Creek watershed, calculated using the HSPEXP software (Lumb et al. 1994).

	Calibration 10/1/96-8/5/01	Recommended Maximum Limits
Total Flow Error	6.7%	+/- 10%
Low Flow Recession	-0.01%	+/- 0.01%
Total flow in 50% lowest flows	8.6%	+/- 10%
Total flow in 10% highest flows	-2.3%	+/- 15%
Seasonal Volume	10.7%	+/- 10%
Storm Volume	-0.6%	+/- 15%
Summer Storm Volume	0.7%	+/- 15%

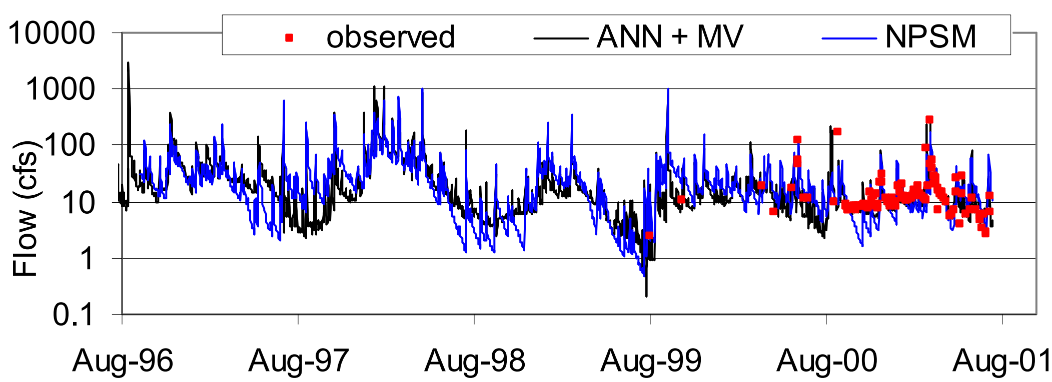

Figure 5.7. Comparison of NPSM predictions, synthetic flows and observed flows for Moore's Creek.

5.3 Formulation of the Water Quality Model

Fecal coliform bacteria are simulated as a dissolved pollutant using the general constituent model of NPSM. Chapter 4 provides a detailed description of the loading assumptions for fecal coliform bacteria in the Moore's Creek watershed, so only a brief summary of source representations will be given here. For current conditions, the Moore's Creek Advanced Wastewater Treatment Plant flows and concentrations were modeled at its average flow of 11 million gallons per day and at its average observed effluent concentration of 17 cfu/100 ml. The Southwood Mobile Home Park plant was modeled at its average outflow volume of 39,000 gallons/day and a concentration of 200 cfu/100 ml, its maximum permitted concentration. Most well-operated facility maintain effluent concentrations well below permit levels. However, since observations of human waste around the Southwood outfall suggest that the facility may not always operate to standards, a maximum concentration was assumed in the model for current conditions. There is no record of fecal coliform permit violations at this facility to support using an average effluent concentration above the permitted level. Any discharge at levels over the permit is assumed to be sporadic, and the possibility of permit violations is currently being investigated by the VADEQ water quality monitoring staff. Any problems found at this facility will be managed through compliance assistance or enforcement. Cattle and wildlife in stream were modeled as direct input to each stream reach, varying by month. Inputs from straight pipes were held constant and modeled as direct inputs to each stream reach. All other nonpoint source loads were modeled as deposited to the land surface where they would be available for wash-off. Wildlife and livestock loads varied by month, depending on population estimates and number of cattle in stream. Sanitary sewer leakage, septic system, and dog fecal coliform loads were held constant.

As a living organism, fecal coliform bacteria will experience die-off once released into the environment. Rates of die-off differ dependent on whether the bacteria are on the land surface or in the stream. A decay rate of 0.045/day was assumed for the fecal coliform bacteria on the land surface. This decay rate is represented in NPSM/HSPF by specifying a maximum surface buildup of nine times the daily loading rate. An in-stream decay rate of 1.15/day was used. In addition, how readily fecal coliform bacteria are washed off of the land surface is dependent on the imperviousness of the surface. Given equal rainfall, more surface flow, and thus more wash-off, occurs on impervious surfaces than on pervious surfaces. This is controlled in the model by specifying the rainfall rate required to remove 90% of the accumulated load (WSQOP) for both pervious and impervious surfaces.

5.4 Calibration Goals for the Water Quality Model

In general, it is more difficult to evaluate fit of a fecal coliform bacteria model than for stream flow. Measured concentrations of fecal coliform bacteria vary dramatically, ranging over many orders of magnitude and can vary quickly from day to day. Thus, the goal of the water quality model will be to reproduce important characteristics of the observed fecal coliform concentrations, if not the exact daily values. The following goals were established for the water quality calibration:

a) Approximate the percentages of concentrations below 200 cfu/100 ml and above 1000 cfu/100 ml. Of the 263 fecal coliform measurements described in Chapter 2, 42.2% are below 200 cfu/100 ml and 14.5% are over 1000 cfu/100 ml.

   These divisions correspond to the two fecal coliform bacteria criteria in the State of Virginia. Concentrations below 200 cfu/100 ml do not contribute to violations of either the geometric standard or the instantaneous standard. Concentrations above 1000 cfu/100 ml represent violations of the instantaneous standards. Values between these bounds may be of a concern if there are sufficient occurrences within 30 days to contribute to violations of the geometric standard.

b) Approximate the seasonal patterns of the observed concentrations.

   Monthly geometric means are shown in Figure 5.8. These were calculated by sorting all 263 concentration observations by month, resulting in 17 to 26 values per month. Even with a geometric mean, a single large value may significantly impact the values shown in Figure 5.8. For instance, the geometric means for September and October are increased by 30% each due a single high value. Nevertheless, the values are consistent with the observation that the June-October period has the highest violation rate of the 30-day geometric mean criterion.

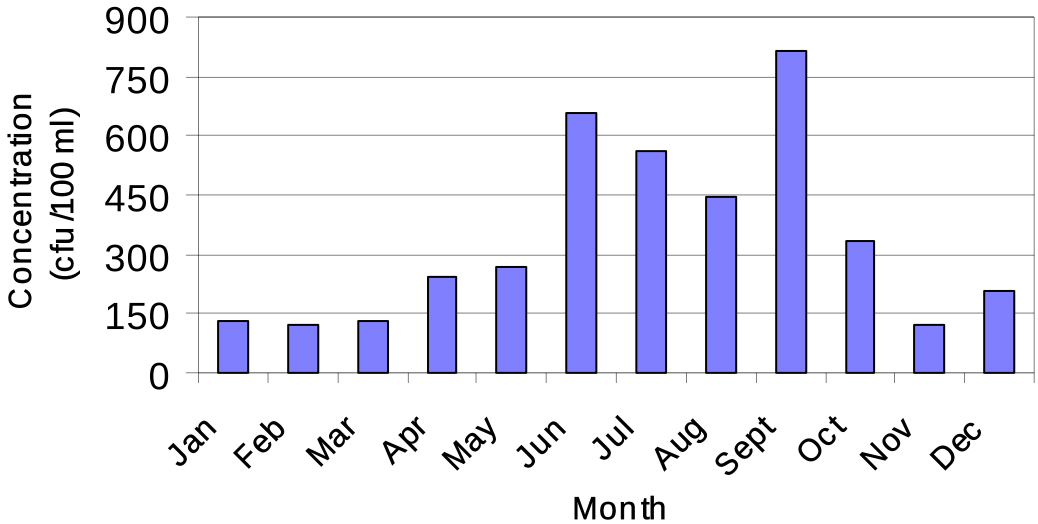

Figure 5.8 Observed monthly geometric means for fecal coliform bacteria in Moore's Creek.

c) Predicted time series of concentrations should reasonably approximate the observed time series.

d) As a secondary goal, the percentage contributions from each main source (wildlife, livestock, dogs, and humans) should be consistent with the general ranges determined in the bacterial source tracking study or BST (Wiggins 2001):

Wildlife contributions 35% to 72%
Livestock contributions 30% to 12%
Dog contributions 4% to 24%
Human contributions 2% to 17%.

In addition, no effort was made to simulate sporadic very high concentrations of fecal coliforms. Concentrations over 10,000 cfu/100 ml represent 2.7% of all observations. Short-term episodic events, such as failure of a septic system near the stream, a break in a sewage line that leaks into the creek, unexpectedly high numbers of livestock in the stream, or discharge of poorly treated waste from the Southwood treatment plant could all contribute to these random spikes. Since there is no way to anticipate when such events will occur, we did not attempt to simulate these rare extreme elevated concentrations. Even if these events continue to occur, by themselves they do not occur with sufficient frequency to cause a stream to be considered impaired.

5.5 Water Quality Model Calibration

The following generally describes the process that was followed in calibration of the water quality model. There were two primary steps. The first initial step made adjustments to the preliminary loading assumptions, as necessary to more accurately represent the system. Then the predictions were fine-tuned by adjusting the values of the model parameters. Simulations with the preliminary loading assumptions predicted fecal coliform concentrations that were consistently an order of magnitude too high. It was determined that the model predictions were very sensitive to assumptions with respect to direct in-stream loads. The percentage of the actual wildlife load to the stream was reduced to the values stated in Chapter 4.

The water quality model calibration was also guided by feedback from the community oversight committee. On review of the preliminary loading assumptions, they felt the overall impact of livestock, especially cattle, was over-estimated and that the numbers of cattle were too high. Furthermore, they felt that human impact may have been under-represented from experience on stream surveys. Consistent with these comments, the initial simulations showed livestock loads dominating wildlife, which was not supported by the BST. To adjust for these problems, the number of cattle was reduced to be more consistent with the numbers in the watershed in recent years, and sites of stream access for cattle were reduced to those shown in Figure 4.1. Furthermore, the failure rate estimate for septic systems was increased to the values described in Section 4.6.1.

Parameters of the water quality model were then adjusted to achieve calibration of the water quality model. Important parameters included the instream degradation rate (FSTDEC) and the wash-off rates (WSQOP). Calibrated values of the parameters of the water quality model can be found in Appendix C. Table 5.6 compares the fecal coliform predictions to the calibration goals. Overall, the calibration goals are well met. Only the contribution from livestock is slightly higher than estimated by the BST. Given the uncertainty in these BST studies, the small deviation from this secondary goal is acceptable. Furthermore, the higher predicted contribution level of livestock maybe indicative of the average contribution of livestock during the calibration period, while the BST, which occurred near the end of the calibration, may be more indicative of the current livestock contributions. Since the number of large livestock is dropping rapidly in the watershed, annual contributions from livestock would also be expected to be changing rapidly. Figure 5.9 shows the predicted fecal coliform concentrations compared to the observed concentrations. The predictions appear reasonable. The 30-day geometric mean criterion of 200 cfu/100 ml is violated 62.8% of the time between 10/1997-7/2001. This corresponds closely to the observed violations of the 30-day geometric mean criterion, based on the VADEQ and Rivanna Water and Sewer Authority monitoring over the same period, which shows violations of the geometric mean standard occurring 60.8% of the time. The only problem period is during the summer of 1999 when the concentrations of fecal coliform bacteria appear over-estimated for an extended period, as shown in Figure 5.10.

Table 5.6 Comparison of fecal coliform simulation to calibration objectives.

Objective	Predictions	Observed
Percentage below 200 cfu/100 ml	50.1%	42.2%
Percentage above 1000 cfu/100 ml	18.2%	14.5%
Months with highest geomeans	June-September	June-September
Total Contribution of Wildlife	40.1%	35% to 72%
Total Contribution of Livestock	34.1%	12% to 30%
Total Contribution of Dogs	19.4%	4% to 24%
Total Contribution of Humans	6.4%	2% to 17%

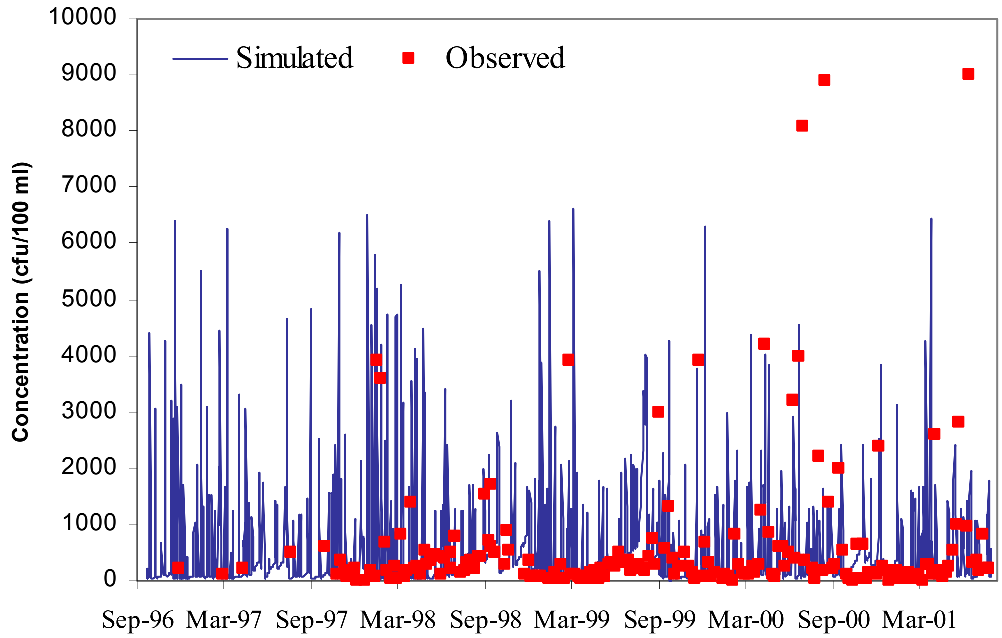

Figure 5.9. Comparison of simulated fecal coliform concentrations to measured concentrations in Moore's Creek.

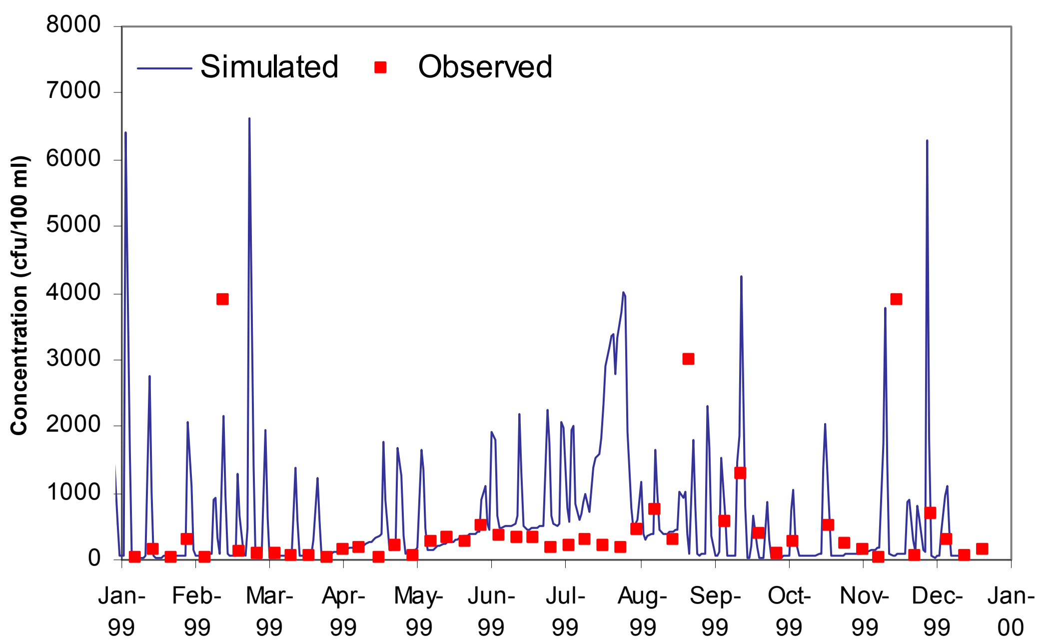

Figure 5.10. Simulated fecal coliform concentrations versus observed concentrations during 1999.

The summer 1999 was an extreme drought, with a return period, based on the 67-year flow record of the Rivanna River at Palmyra, of approximately 17 years. The assumptions used to build the water quality model were based on more commonly occurring conditions. Most importantly, small magnitude errors in flow predictions will have a much higher percentage error under low flow conditions. During the summer of 1999, the synthetic flow predictions for Moore's Creek averaged 1.8 times greater than the simulated flows, with individual days with ratios as high as 5.6 times more flow in the synthetic series as compared to the predicted flows. During baseflow conditions of a drought, under-estimations of flow will be directly correlated to under-estimation of dilution. Thus, these small magnitude flow errors would cause the predicted concentrations to be nearly doubled on average, with some days concentrations as much as 5.6 times too high. Although efforts were made to increase the simulated flows during the summer 1999, this could not be achieved without damaging the hydrological calibration at other times.

The water quality calibration shown in Figure 5.9 was used as the base case for current conditions for the load allocations. The selection of the allocation period, with deference to the issues related to the drought of 1999, is described in Chapter 6.

Chapter 6: TMDL Allocations

6.0 Introduction

Chapter 2 described the observations of excess fecal coliform bacteria in Moore's Creek, which cause the water quality impairment. Chapters 4 and 5 detailed the loading assumptions and model development and calibration to create a numerical model that describes the flow and transport processes in Moore's Creek. The model described in Chapter 5 simulates the water quality conditions in the Moore's Creek watershed under the current impaired conditions.

The next step in the TMDL development is to determine loading scenarios that will meet the TMDL goal of maintaining the 30-day geometric mean of fecal coliform concentrations at or below 200 cfu/100 ml in the future. The fecal coliform load in the TMDL is divided into three categories. One is the margin of safety (MOS). A MOS will be explicitly added by achieving concentrations 5% below the 30-day geometric mean criterion of 200 cfu/100 ml. The remaining allowable 190 cfu/100 ml is divided between the allowable loading from point sources (termed the waste load allocation, WLA) and the allowable loading from nonpoint sources (termed the load allocation, LA). Various combinations of reductions in current loads of fecal coliform bacteria are demonstrated, and an overall load allocation is recommended. Future conditions are described below.

6.1 Future Conditions

The Moore's Creek watershed has been developing and part of the watershed falls in the designated growth area for Albemarle County. Based on the U.S. Census, the county grew by 16.2% between 1990 and 2000. For future conditions, we will assume that this rate of increase will continue and that by 2010 the population in the Moore's Creek watershed will have increased by another 16.2%. As is consistent with the county plan, we further assume that land use changes will occur in response to population growth, causing a 16.2% increase in developed areas (urban and residential areas).

Based on the designated growth area, this increased development will not be equally distributed within the Moore's Creek watershed. A land use coverage of the county growth area, provided by the Thomas Jefferson Planning District Commission, was used to determine reasonable modifications in the current land use coverage for the Moore's Creek watershed. A total of 6610.4 acres (29.5%) of the Moore's Creek watershed is designated as part of the growth area. The land uses in the growth area map were grouped into urban or residential categories. The residential category included both medium-density and low-density residential. The growth area map was then compared to the subwatershed map to determine how much of the growth area urban and residential categories fell into each subwatershed (Table 6.1). The added acreage of developed areas was distributed between subwatersheds according to the percentages shown in Table 6.1. The distribution of newly developed areas is shown in Table 6.2. Although for Moore's Creek watershed the percentage increases in urban, low-density residential and medium-density residential are all near 16.2%, the percentage growth of these land uses within a subwatershed varies significantly (Table 6.2).

Table 6.1 Acreages and percentages of the growth area land use categories by subwatershed.

SW#	URBAN		RESIDENTIAL	
	acres	percentage	acres	percentage
1	1060.2	32.8	932.2	27.6
2	76.8	2.4	293.8	8.7
3	57.3	1.8	67.8	2.0
4	5.0	0.2	38.5	1.1
5	416.2	12.9	88.4	2.6
6	181.7	5.6	1207.3	35.7
7	74. 4	2.3	0	0.0
8	7.6	0.2	331.3	9.8
9	201.5	6.2	0	0.0
10	800.6	24.8	242.1	7.2
11	347.2	10.8	180.4	5.3
Sum	3228.6	100.0	3381.8	100.0

Table 6.2 Distribution of newly developed areas in the Moore's Creek watershed in 2010 and percentage increases in each land use.

Subwater-shed	Urban		Low-density Residential		Medium-density Residential	
	Acres	%	Acres	%	Acres	%
1	117.8	43.7	98.0	15.6	85.4	71.2
2*	8.5	7.7	57.8	67.5	0.0	0.0
3	6.4	4.4	7.1	1.3	6.2	61.1
4*	0.6	10.3	0.0	0	7.5	2119
5	46.2	24.3	9.3	14.2	8.1	20.0
6	20.2	65.7	127.0	118.2	110.6	24.7
7	8.3	283.3	0.0	0.0	0.0	0.0
8	0.8	7.2	34.8	45.8	30.4	394.8
9	22.4	11.8	0.0	0.0	0.0	0.0
10	88.9	8.3	25.5	62.7	22.2	2.7
11	38.6	20.4	19.0	60.7	16.5	4.8
Sum:	358.7	16.2	378.5	17.2	286.9	15.0

*Total residential area increase in this subwatershed assigned to a single residential density, since under current conditions all residential area in subwatershed in a single density.

As the acreage of developed area increase, non-developed acreage (forest and grassland) must decrease. From comparison of the growth area map to the current land use map, it was determined that the newly developed residential area came from 76.8% forest and 23.3% grassland, while the new urban development displaced 62.3% forest and 37.7% grassland. These percentages were applied to each subwatershed to determine the requisite decrease in undeveloped areas. Adding the newly developed land shown in Table 6.2 to the existing land uses (Table 3.2) and making the corresponding reductions in undeveloped lands results in the future land use distributions for the Moore's Creek watershed, as shown in Table 6.3.

For the base case for future land-based nonpoint source loads, the fecal coliform loading rates (cfu/acre/month) for most land use categories are assumed to be unchanged. The exception is for grasslands, which includes pastures. The population of large livestock (cows and horses) in the Moore's Creek watershed has dropped by about 87% over the last decade. As described in section 4.5, an average livestock population was used for the calibration period. However, due to the rapid loss of livestock, the grassland loading rate by the end of the calibration period would be significantly less than the average rate used for calibration. Therefore, the future loading rate for grasslands was calculated using the livestock population in 2002, as determined by the Albemarle County Farm Bureau count plus animals at the stockyard. This results in grassland loading rates that average 53% of those used during calibration. See Appendix D for details.

Table 6.3. Land use distributions (in acres) for the Moore's Creek watershed in 2010.

SW#	Forest	Low-Density Residential	Med-Density Residential	Grassland	Urban	Water	Total
1	366.9	727.8	205.4	437.0	387.3	26.1	2150.5
2	1739.9	116.5	26.9	91.2	119.3	79.7	2173.5
3	2591.0	555.5	16.4	343.1	150.3	1.7	3658.1
4	20.0	4.0	3.9	9.1	6.3	0.0	43.3
5	901.3	75.0	48.6	388.7	236.5	5.8	1656.0
6	1267.2	234.4	559.2	289.6	50.9	27.8	2429.2
7	2997.6	571.7	15.5	659.1	11.2	8.9	4264.0
8	892.5	110.9	38.1	411.1	12.0	7.8	1472.4
9	344.0	38.7	106.7	122.1	211.6	3.4	826.6
10	406.2	66.1	840.1	226.9	1159.5	14.9	2713.7
11	317.3	50.2	362.3	34.2	227.6	4.4	996.1
Total	11844.0	2550.9	2223.0	3012.2	2572.8	180.6	22383.4

For the base case, future loads of coliform bacteria deposited directly in Moore's Creek will come from four sources: the two point sources and cattle and wildlife in the stream. Both point sources were modeled as discharging at their maximum permitted concentration of 200 cfu/100 ml and their expected average future outflows. The outflow from the Moore's Creek wastewater treatment plant is expected to increase to 12 million gallons per day with the increase in population, while the flow volume from Southwood facility should remain unchanged. The direct load from cattle in stream was also reduced due to loss of livestock from the stream access area in subwatershed 4. Wildlife deposition directly to the stream was assumed unchanged from that determined for the present case simulations. Although some modifications to the wildlife populations and distribution are expected to be induced by land use alterations, some wildlife populations will decrease while others will increase. Deer numbers in the Moore's Creek watershed would increase by 32 deer given their preference for residential areas. Raccoon numbers would also increase, given that they do live in residential areas, but do not utilize open grasslands. Beaver numbers would remain unchanged. The total number of geese would also be unchanged although they would redistribute between subwatersheds, preferring less developed areas. Muskrat numbers would decrease since they do not utilize urban areas. Therefore changes in wildlife numbers tend to offset, leaving only a small impact, relative to the model uncertainty, on the total wildlife load deposited directly in the stream.

6.2 Allocation Period

The period from 10/1996-8/2001 was selected as the calibration period for the hydrological and water quality model, because that corresponds to the period over which there were significant water quality and flow observations on Moore's Creek. However, as was shown at the end of Chapter 5, that period includes the drought of 1999, which was an unusual hydrological period (return period of 17 years) during which the water quality model performed poorly. If this extended period of over-estimates was included in the allocation period, it would become the limiting conditions controlling future allocations.

Therefore, the allocation period was selected as 10/1990-9/1998. This 8-year period includes multiple typical hydrologic years and periods of low and high flows. Figure 6.1 shows a hydrological validation of the NPSM/HSPF model during the allocation period, as compared to synthetic flow data. (No actual flow observations exist during this period). Current land use information was used for the validation test. The model predictions follow the synthetic predictions well. Validation statistics are shown in Table 6.4. Since comparisons are to synthetic data only, the acceptable error measures were broadened. Much of the seasonal error and summer storm volume error is due to a few storm events with significant deviations between the model predictions and the synthetic flows. These errors could be due to inaccurate synthetic information, localized storm events for which the regional gauges are poor predictors, or errors in the historical precipitation data. Since the goal of the allocation simulations is to estimate performance of load reductions given a weather pattern and resultant flows that are reasonable for this watershed, these predictions were deemed acceptable and no efforts were made to recalibrate model or adjust historical weather inputs. As can be seen in Figure 6.2, the water quality predictions during the allocation period reproduce the observed fecal coliform concentrations well.

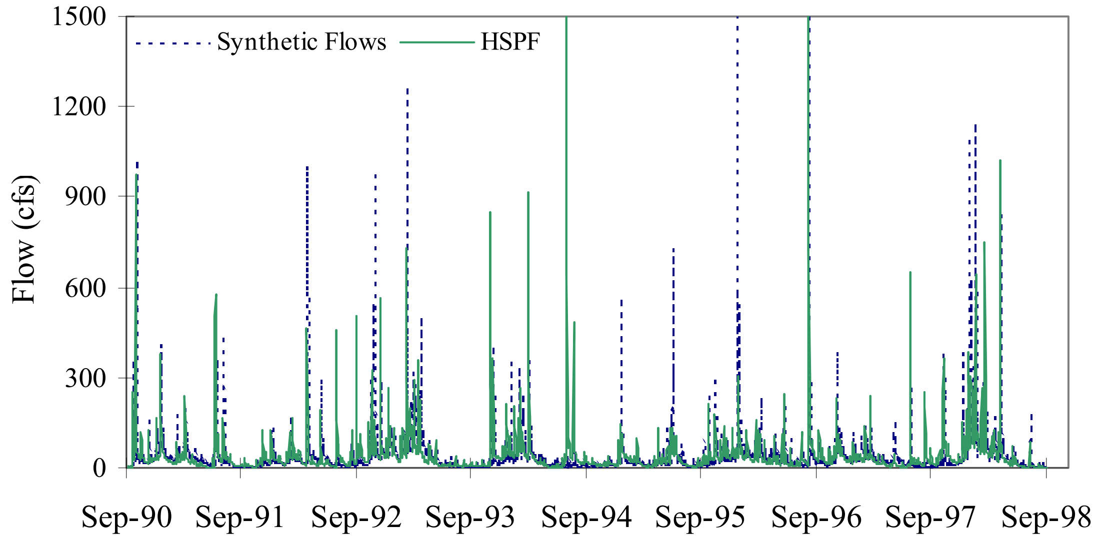

Figure 6.1. Comparison of flow predictions to the synthetic flows for the allocation period.

Table 6.4. Flow validation measures for the Moore's Creek watershed, calculated using the HSPEXP software (Lumb et al. 1994), for the allocation period.

	Validation 10/1990-9/1998	Acceptable Errors
Total Flow Error	-1.5%	+/- 10%
Low Flow Recession	0.0%	+/- 0.01%
Total flow in 50% lowest flows	0.3%	+/- 10%
Total flow in 10% highest flows	-5.7%	+/- 15%
Seasonal Volume	28.1%	+/- 30%
Storm Volume	-6.5%	+/- 15%
Summer Storm Volume	31.4%	+/- 30%

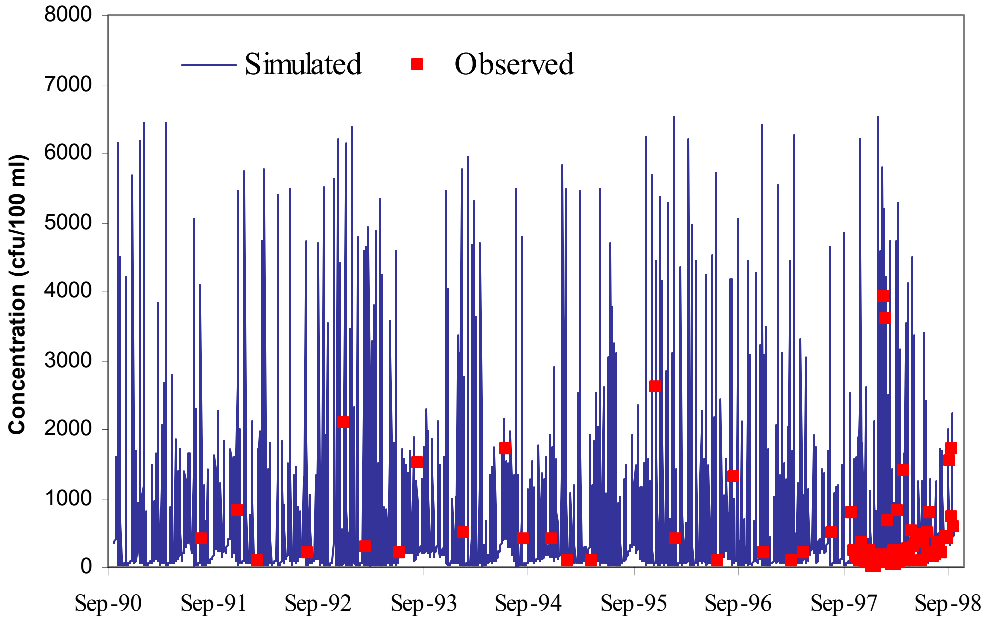

Figure 6.2 Validation of fecal coliform bacteria predictions during the allocation period.

6.3 Allocation Scenarios

While a TMDL is the greatest amount of a pollutant that a waterbody can receive without violating applicable water quality standards, an allocation scenario describes how the load can be divided among sources. The selected TMDL allocation scenario must result in water quality levels that satisfy the TMDL water quality goals. Other issues that should be considered in selection of a TMDL allocation scenario are achievability, cost-effectiveness, and equity between sources. Allocation scenarios are described in terms of the required reduction in each source's contribution to the in-stream fecal coliform bacteria levels.

For the allocation modeling, the historical weather for the 10/1990-9/1998 was combined with the projected future land use of Moore's Creek in 2010. Various allocation scenarios were modeled with the goal of meeting the 30-day geometric mean for fecal coliform bacteria with a 5% margin of safety. The base case, before load reductions occur, is shown as scenario 0 in Table 6.5. As can be seen, with the base case loads, violations of the geometric standard would occur 46.3% of the time.

Table 6.5 Allocation scenarios for the Moore's Creek watershed. In all cases, point sources are discharging at their maximum permitted levels.

Scenario Number	Percentage Reductions in						% of 30-day Geo-mean over 190 cfu /100 ml	Max value of 30-day Geo-mean (cfu/ 100 ml)
	Direct Cattle	Straight pipes	Septic NPS	Urban Sewer Leakage	Direct Wildlife	Other NPS Loads		
0	0	0	0	0	0	0	46.3	629
1	100	0	0	0	0	0	46.2	624
2	0	100	0	0	0	0	6.5	341
3	0	0	100	0	0	0	44.0	604
4	0	0	0	100	0	0	45.7	620
5	0	0	0	0	100	0	34.2	497
6	0	0	0	0	0	100	15.9	440
7	100	100	100	100	0	0	4.4	308
8	100	100	100	100	0	50	0.9	224
9	100	100	100	100	50	0	1.1	228
10	100	100	100	100	25	50	0.03	191
11	See Table 6.6						0.0	189

The first step in the analysis was to remove each of the major nonpoint source categories to demonstrate their relative importance. (In all cases, the point source loads remain at their legally permitted maximum levels, as described in section 6.1.) The results are shown in scenarios 1-6 in Table 6.5. Due to the relatively small number of cattle with stream access, removal of direct deposition of cattle waste to the stream in itself has little impact on the overall water quality of Moore's Creek. Likewise, removal of all failing septic systems or sewer system leakage has relatively little impact since they each represent a small percentage of the overall nonpoint source load of fecal coliform bacteria. As is shown in Figure 6.3, more substantial reductions in the 30-day geometric mean result from removal of straight pipes, direct deposition of wildlife waste to the stream, or other land-based nonpoint source pollution (from livestock, dogs, and wildlife). However, the TMDL goal cannot be met by removal of any individual nonpoint source type. The remaining scenarios will combine reductions of more than one source type.

Scenario 7 (Table 6.5) combines removal of all non-permitted human bacterial loads (straight pipes, sewer system leakage, and failing septic systems) with exclusion of cattle from the stream. This scenario reduces the violations of the TMDL goal to less than 5%, although the maximum value of the 30-day geometric mean is still substantially above the goal of 190 cfu/100 ml. Since untreated human waste should not be reaching the stream and allowing livestock access to the stream is an inappropriate management practice, these two steps will be assumed in all other scenarios.

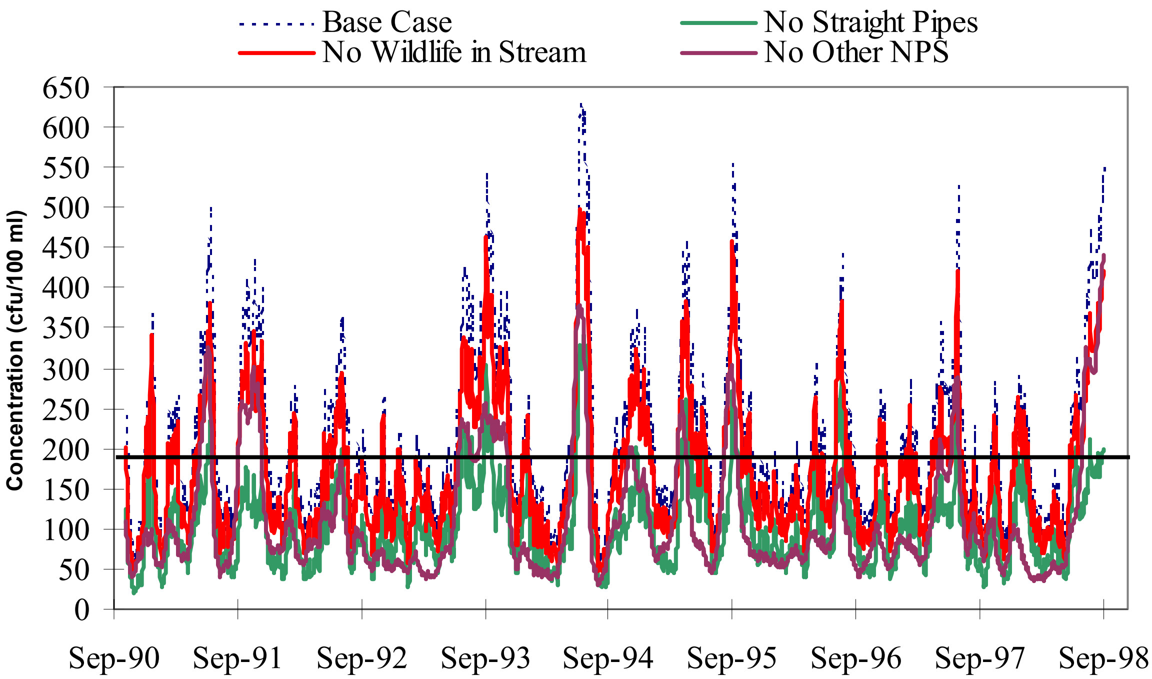

Figure 6.3 Resultant 30-day geometric mean concentrations resulting from removal of a single source type. Black line is the TMDL goal of 190 cfu/100 ml.

Additional reductions in load (beyond scenario 7) must come from direct deposition of wildlife waste to the stream or the remaining land-based nonpoint source loads. The next two scenarios demonstrate the relative impacts of reductions to these two loads. For scenario 8, in addition to the load reductions from scenario 5, all remaining land-based nonpoint source load will be reduced by 50%. This scenario is just for demonstration, since it would constitute reducing the remaining human-controlled loads (dogs and livestock) by over 87%, which is not realistic. However, even if this level of reduction in the remaining land-based nonpoint source loads were feasible, it would not meet the TMDL goal, as shown in Table 6.5. Conversely, a large reduction in the direct deposition of wildlife waste to the stream, without corresponding reductions in land-based nonpoint source loads, could not meet the TMDL standard (Scenario 9 in Table 6.5). Thus, all other scenarios will consider combinations of reductions in the direct deposition of wildlife waste to the stream and the remaining land-based non-point source loads. Scenario 10 (Table 6.5) combines a 25% reduction in the direct deposition of wildlife wastes to the stream with a 50% reduction in all land-based non-point source loads. While this scenario nearly meets the TMDL goal, it requires an unattainable 50% reduction in all remaining land-based nonpoint sources (which includes wildlife).

Working from Scenario 10, a more detailed allocation plan (Scenario 11 as shown in Table 6.6), with reductions by subwatershed, was developed. As in previous scenarios, all non-permitted human sources were removed and cattle were removed from the stream. Some subwatersheds show zero reductions in one or more of these sources simply because there were no such sources in the subwatershed under base case conditions. A 40% reduction in the direct deposition of wildlife waste to the stream is assigned in all subwatersheds. The reduction to the remaining land-based nonpoint source contributions is then allocated by subwatershed and by land use. No reduction in the contribution of fecal coliform bacteria from forest was assumed, since forest loads are completely wildlife generated and are essentially background levels. Reductions in contributions from residential lands were assigned to subwatersheds 5, 6, 9, 10, and 11, which are both along or near the main stem of Moore's Creek and are the most developed subwatersheds with significant urban and medium-density residential areas. For subwatersheds with little or no livestock remaining, no reductions in contributions were assigned to grasslands, since the major contributor to the grassland loads in these areas would be wildlife. For most the other subwatersheds that still held livestock, a 30% reduction in grassland contribution was assigned. The only exception was for subwatershed 9 where it was noted that there are a large number of goats in the area above the water quality monitoring station. Many of these animals live in and around the stockyard, including feral animals in the area. If the herd of feral animals is removed and best management practices are put in place around the stockyard, the grassland loading to subwatershed 9 could be reduced substantially. For subwatersheds with a significant urban area, urban contributions were reduced from 45% to 50%, with the highest reductions assigned to the subwatersheds near the main stem of Moore's Creek. As shown in Table 6.5 and Figure 6.4, Scenario 11 satisfies the TMDL goal.

Table 6.6. Scenario 11 load reductions by subwatershed.

	Percentage Reductions in Contributions from:									
						Other NPS: By Land Use				
SW#	Direct Cattle	Straight Pipe	Septic NPS	Sewer Leak-age	Direct Wildlife	Forest	Low-Density Resid.	Med-Density Resid.	Grass-land	Urban
1	0	100	100	100	40	0	0	0	0	45
2	0	0	100	0	40	0	0	0	0	45
3	100	100	100	0	40	0	0	0	30	45
4	0	0	0	0	40	0	0	0	0	0
5	0	0	100	100	40	0	30	30	30	50
6	0	100	100	100	40	0	40	40	30	45
7	0	100	100	0	40	0	0	0	30	0
8	0	0	100	0	40	0	0	0	30	0
9	0	0	100	100	40	0	50	50	85	50
10	0	0	0	100	40	0	50	50	0	50
11	0	0	0	100	40	0	50	50	0	50

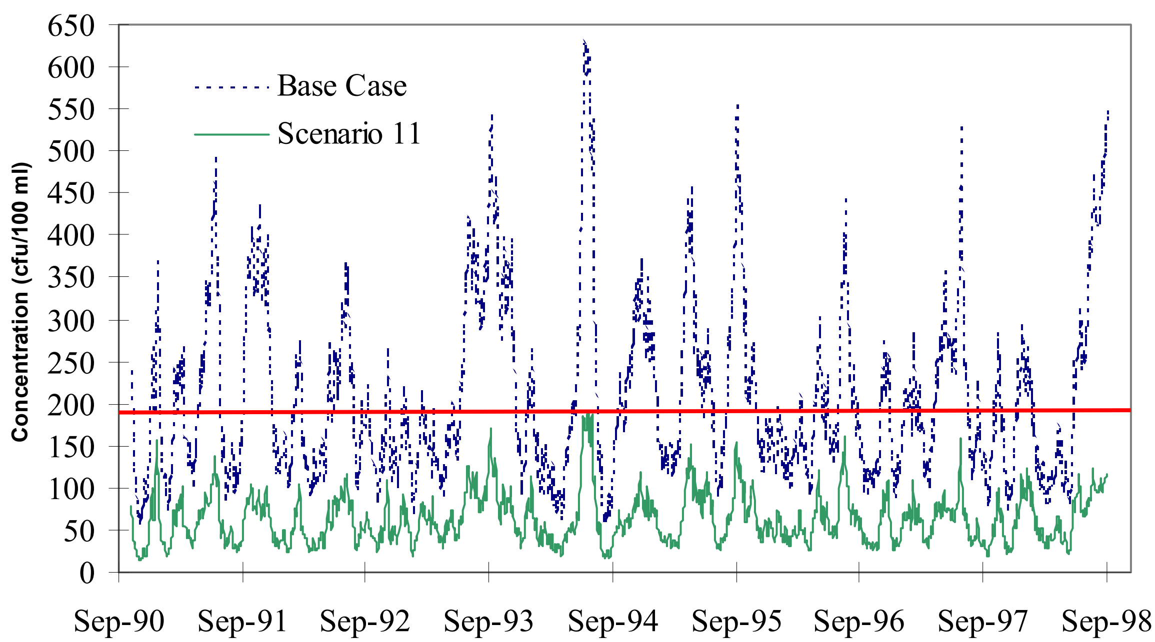

Figure 6.4. Comparison of 30-day geometric mean over the allocation period for base case conditions and for Scenario 11. Red line is the TMDL goal of 190 cfu/100 ml.

Since Scenario 11 satisfies the TMDL water quality goal of 190 cfu/100 ml or less at all times and utilizes potentially obtainable reductions in contributions, it is selected as the TMDL allocation. The corresponding TMDL load allocations for the Moore's Creek watershed are shown in Table 6.7. The allocations are based on the total contributions to the stream. Each point source is allocated its permitted waste load allocation (WLA). The contribution from the Southwood treatment plant is shown under WLA(SW), while the contribution from the Moore's Creek wastewater treatment plant is shown under WLA(MC). These allocations require no reduction from the permitted point source loads, although any episodic permit violations are assumed eliminated. Table 6.7 also shows the total allocation to nonpoint sources (ΣLA) and the load reserved as a margin of safety (MOS). To meet this TMDL, the required reduction of all nonpoint source contributions (direct to stream and land based; human controlled and background) is 31.8% compared to current contributions or 34.6% compared to the base case future contributions.

Table 6.7 TMDL load allocations (cfu/day)

WLA(SW)	WLA(MC)	ΣLA	MOS[a]	TMDL
0.01×10^{13}	3.30×10^{13}	61.41×10^{13}	3.41×10^{13}	68.13×10^{13}

[a]Five percent of the TMDL

The selected allocation scenario described in Table 6.6 may be conservative if the upstream point source (Southwood) regularly discharges at levels below its maximum permitted level. Since the allocation assumes that the point sources are discharging at their maximum permitted levels, any excess load assigned to the point sources takes away available loading from other sources. Thus, the reductions required from wildlife and the other nonpoint source land loads may need adjustment as staged implementation occurs and if monitoring data reflects obtainment of water quality standards. The staged implementation process is described in the next chapter.

Chapter 7: TMDL Implementation and Reasonable Assurance

7.0 Introduction

The ultimate goal of a TMDL project is to establish a path that can reasonably be expected to improve water quality and maintain a watershed in an unimpaired state. Development of the loads corresponding to the TMDL for the watershed, as was done in Chapter 6, is just the first step in the process. Subsequently, a management plan or implementation plan that will result in the TMDL loads shown in Table 6.7 must be developed and then the plan must be implemented. Concurrently, continued monitoring of the stream should continue to be able to evaluate the effectiveness of the management plan and to allow for re-evaluation and modification of the TMDL as necessary. These steps and the infrastructure needed to support them are described in the following sections.

7.1 TMDL Implementation

The Virginia Department of Environmental Quality (VADEQ) intends for this TMDL to be implemented through best management practices (BMPs) in the watershed. Implementation will occur in stages. The benefits of staged implementation are:

1. as stream monitoring continues to occur, it allows for water quality improvements to be recorded as they are being achieved;
2. it provides a measure of quality control, given the uncertainties which exist in any model;
3. it provides a mechanism for developing public support;
4. it helps to ensure the most cost effective practices are implemented initially; and
5. it allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan as outlined below. While specific goals for BMP implementation will be established as part of the implementation plan development process, some general guidelines and suggestions are outlined below.

In general, the Commonwealth intends for the required reductions to be implemented in an iterative process that addresses the sources with the largest impact on water quality first. A potential Phase 1 goal for Moores Creek could be reduction in the violations of the 30-day geometric mean criterion to less than 10% of the time. Removal of all straight pipes (Scenario 2 in Table 6.5) and any episodic permit violations at the Southwood Treatment plant would reduce the violations of the 30-day geometric mean standard to 5.0% of the time.

7.2 Follow-up Monitoring

Sampling at the Rivanna Water and Sewer Authority (RWSA) sampling site on Moore's Creek will continue. The RWSA will continue to sample the stream, in compliance with its VPDES permit, on a weekly basis. Furthermore, the VADEQ will continue to monitor at this site to evaluate the effectiveness of the TMDL implementation plan. Creek stage can also be recorded at the time of sampling. Thus the amount of future information with respect to stream water quality is expected to be good. If stage levels are recorded at least weekly that will provide some flow data for future modeling of the stream and evaluation of the performance of the current stream model.

7.3 Reasonable Assurance for Implementation

7.3.1 Regulatory Framework

Section 303(d) of the Clean Water Act and current USEPA regulations do not require the development of implementation strategies. However, including implementation plans as a TMDL requirement has been discussed for future federal regulations. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act directs VADEQ in section 62.1-44.19.7 to "develop and implement a plan to achieve fully supporting status for impaired waters".   The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated cost, benefits and environmental impact of addressing the impairments. USEPA outlines the minimum elements of an approvable implementation plan in its 1999 "Draft Guidance for Water Quality-Based Decisions: The TMDL Process" (USEPA, 1999a). The listed elements include implementation actions/management measures, time line, legal or regulatory controls, time required to attain water quality standards, monitoring plan and milestones for attaining water quality standards. Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of VADEQ, VADCR and other cooperating agencies.

Once developed, VADEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's 's Section 303(e). In response to a Memorandum of Understanding between USEPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to the USEPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

7.3.2 Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 funds, as specified in the Clean Water Act. Virginia has developed a Unified Watershed Assessment that identifies priorities, and watershed restoration efforts within priority watersheds are eligible for Section 319 funding. Future increases in Section 319 funding will be targeted towards TMDL implementation and watershed restoration. Other potential sources of funding include U.S. Department of Agriculture's Conservation Reserve Enhancement Program, the state revolving fund program, and the Virginia Water Quality Improvement Fund.

Chapter 8: Public Participation

8.0 Overview

Public involvement is not only a requirement of TMDL development (USEPA 2002), but it is also key to successful TMDL implementation. In addition to the three required public meetings, a TMDL advisory committee was convened by the Thomas Jefferson Planning District Commission (TJPDC). Both the Rivanna River Basin Roundtable and TJPDC staff were asked to brainstorm who should be invited to join the committee, and an open invitation was also sent to the Rivanna Roundtable e-mail list. The list includes representatives of a number of organizations with interest in the Rivanna and interested citizens. Ultimately 12 people were named to the advisory committee by the TJPDC, including representatives from Albemarle County, the City of Charlottesville, the Rivanna Water and Sewer Authority, the Thomas Jefferson Soil and Water Conservation District, the Albemarle County Farm Bureau, the Southern Environmental Law Center, the Fry's Springs and Belmont Neighborhood Associations, and several other interested citizens.

8.1 Meetings

The assembly of the advisory committee was still in progress as of the first public meeting on June 7, 2001, held at the Albemarle County offices in Charlottesville. The public notice for this meeting appeared in the Virginia Register on May 21, 2001. The meeting announcement was also posted on the TJPDC website and sent to a large e-mail list including both the Rivanna and Natural History Roundtable lists and Charlottesville and Albemarle elected and appointed officials, with encouragement to redistribute. Presentations by David Lazarus of VADEQ, William Keeling of VADCR, and Teresa Culver of University of Virginia covered the basics of what a TMDL is, the steps in the TMDL process, and the specifics of TMDL development for Moore's Creek. There were approximately 20 people in attendance, including a number of those who became part of the advisory committee. Copies of the presentation materials were available at the meeting and were posted on the TJPDC website afterwards. The public comment period ended on June 22, 2001. No written comments were received.

The advisory committee met for the first time on September 21, 2001. This was basically an introductory meeting in which ground rules were approved and the purpose of the committee, the nature of the watershed, and the results of bacterial source tracking study (Wiggins 2001b) were discussed. An attempt to organize a tour of the watershed failed, but several members toured the watershed individually using directions and maps provided. It was agreed to meet again shortly after the second public meeting.

The second public meeting was held on November 15, 2001 at the Jefferson Preschool in Charlottesville. The public notice appeared in the Virginia Register on November 5, 2001. The meeting notice was again posted on the TJPDC website and distributed to the e-mail list. Public service announcements were also sent to the Daily Progress newspaper and WMRA radio station, and the meeting was announced at the November meeting of the Thomas Jefferson Soil and Water Conservation District. At this public meeting, Teresa Culver presented an update on the progress of the TMDL, discussing both the hydrologic model and the loading assumptions. She announced that details of the loading assumptions would be available later for review. There were again about 20 people in attendance, including members of the advisory committee. Copies of the presentation materials were available at the meeting and were posted on the TJPDC website afterwards. A summary of the questions and answers at this meeting was compiled by VADEQ staff and is available from the VADEQ Valley Regional office in Harrisonburg, VA. The public comment period ended on November 30, 2001. No written comments were received.

The second advisory committee meeting was held on November 27, 2001. Attendees discussed the public meeting but decided that they had no comments to make at that time, preferring to wait until the detailed loading assumptions were available. They also heard a presentation by Jim Palmborg of the Charlottesville Public Works Department on recent and planned work in the sewer system in the Moore's Creek watershed. It was agreed that the next meeting would be scheduled after the assumptions became available.

Detailed loading assumptions were received by TJPDC staff in late January and immediately passed to the committee for their review. The third advisory committee meeting was scheduled for February 12, 2002. Discussion covered all types of fecal input but particularly focused on human and livestock inputs. Two pages of comments were typed up by TJPDC staff, reviewed by the committee, and submitted to Dr. Culver. Committee members not present or unable to finish their evaluation within a couple of days after the meeting were encouraged to submit comments separately. The loading assumptions were also posted to the TJPDC website.

The third and final public meeting was held on March 25, 2002 at the Jefferson Preschool in Charlottesville. The public notice appeared in the Virginia Register on March 11, 2002. In addition to website and e-mail advertisement, public service announcements were submitted to WMRA and WINA radio stations and WVIR television station's "Community Calendar," and an ad featuring a map of the watershed was run in the Daily Progress newspaper on Sunday, March 17. However, attendance was similar to the first two meetings. The bulk of the meeting consisted of Teresa Culver's presentation of the draft TMDL. There were also short presentations by Sandra Mueller of VADEQ, giving a brief background on TMDLs, and by William Keeling of VADCR, discussing implementation. Copies of the presentation materials were available at the meeting. The draft TMDL was made available on the TJPDC's website and distributed to the advisory committee two weeks before the meeting.

The advisory committee met for the last time on March 26, 2002, with Dr. Culver and her graduate assistants, to discuss their remaining concerns about the TMDL. On the basis of their comments at that meeting, some changes in fecal loads were made in the model, and the results submitted to the committee for a final review. Their comments were also typed up by TJPDC staff and submitted to VADEQ.

The public comment period ended April 19, 2002.

Appendix A: Seasonal wildlife load calculations by subwatershed

Table A1 Number of Deer by land use in each Subwatershed

	Residential Deer (All Year)		Forest Deer (All Year)		Total Deer (All Year)
Density (#/acre)	0.07		0.05		
Sub-Water-shed	Area of Habitat (acres)	# of Deer = .07 * Area	Area of Habitat (acres)	# of Deer = .05 * Area	
1	749.7	53	1105.2	55	
2	85.6	6	1897.4	95	108 101
3	558.5	39	2953.9	148	187
4	0.4	0	37.2	2	2
5	106.2	7	1353.7	68	75
6	555.9	39	1814.7	91	130
7	587.2	41	3664.9	183	225
8	83.8	6	1369.6	68	74
9	145.4	10	488.6	24	35
10	858.6	60	769.7	38	99
11	377.0	27	425.6	21	48

Table A2. Calculation of number of geese by subwatershed.

Sub-water shed	Geese Habitat (acre)	% Habitat in Subwatershed (A)	# of Geese = A * 193
1	667.9	14.3%	28
2	441.9	9.5%	18
3	426.1	9.1%	18
4	12.9	0.3%	1
5	483.3	10.3%	20
6	547.9	11.7%	23
7	850.2	18.2%	35
8	511.3	10.9%	21
9	187.6	4.0%	8
10	415.3	8.9%	17
11	128.5	2.7%	5
Total	4672.92		193[a]

[a] Total Geese = 5.52 geese/sq. mile * 34.92 sq. miles in watershed

Table A3. Monthly Distribution of Raccoon Number in each Subwatershed

		Aug – Mar (A)	Apr – May (B)	June – July (C)	Annual average
Sub-Water-shed	Area of Habitat (acres)	0.063/acre habitat	0.094/acre habitat	0.070/acre habitat	0.67*A + 0.17*B+ 0.16*C
1	620.0	39	58	44	43
2	1384.4	87	130	97	96
3	1338.0	84	125	94	92
4	32.3	2	3	2	2
5	512.4	32	48	36	35
6	1352.5	85	127	95	93
7	2052.2	128	192	144	142
8	540.9	34	51	38	37
9	342.5	21	32	24	24
10	1481.2	93	139	104	102
11	533.3	33	50	37	37

Table A4. Monthly Distribution of Muskrat Number in each Subwatershed

		Nov – Feb (A)	Mar – Apr Aug – Oct (B)	May (C)	June-July (D)	Annual average
Sub-Water-shed	Area of Habitat (acres)	2/acre habitat	5/acre habitat	9/acre habitat	10/acre habitat	0.33*A+0.42*B +0.08*C +0.17*D
1	29.5	59	147	265	295	152
2	58.5	117	292	526	585	302
3	34.1	68	170	307	341	176
4	2.1	4	10	19	21	11
5	14.1	28	71	127	141	73
6	59.0	118	295	531	590	305
7	74.8	150	374	673	748	387
8	24.5	49	123	221	245	127
9	8.4	17	42	75	84	43
10	43.0	86	215	387	430	222
11	14.8	30	74	133	148	76

Table A5. Seasonal Distributions of Beaver by Subwatershed

	In Streams				On Lakefront				Annual Average
		Oct-Mar	Apr-May	Jun-Sept		Oct-Mar	Apr-May	Jun-Sept	0.5*(A+D)+ .17*(B+E) +.33* (C+F)
Sub-water-shed	Stream miles	3 per mile (A)	10 per mile (B)	4.8 per mile (C)	Lake-shore miles	2.4 per mile (D)	8 per mile (E)	3.9 per mile (F)	
1	2.01	6	20	10	1.85	4	15	7	17
2	3.07	9	31	15	4.36	10	35	17	31
3	4.81	14	48	23	0.00	0	0	0	23
4	0.26	1	3	1	0.00	0	0	0	1
5	1.41	4	14	7	0.00	0	0	0	7
6	5.19	16	52	25	2.22	5	18	9	34
7	8.87	27	89	43	0.43	1	3	2	44
8	3.07	9	31	15	0.00	0	0	0	15
9	1.37	4	14	7	0.00	0	0	0	7
10	5.51	17	55	26	0.53	1	4	2	28
11	1.99	6	20	10	0.00	0	0	0	10

Table A6. Monthly Distribution of Daily Raccoon Fecal Coliform Production Rate (10^{10} cfu/day)

	Aug – Mar		Apr – May		June – July		Annual Average	
Sub-Water-shed	# of raccoon	Daily Load	# of raccoon	Daily Load	# of raccoon	Daily Load	# of raccoon	Daily Load
1	39	3.2	58	4.7	44	3.6	43	3.5
2	87	7.0	130	10.6	97	7.9	96	7.8
3	84	6.8	125	10.2	94	7.7	92	7.5
4	2	0.2	3	0.2	2	0.2	2	0.2
5	32	2.6	48	3.9	36	2.9	35	2.9
6	85	6.9	127	10.3	95	7.7	93	7.6
7	128	10.4	192	15.7	144	11.8	142	11.5
8	34	2.8	51	4.1	38	3.1	37	3.0
9	21	1.7	32	2.6	24	2.0	24	1.9
10	93	7.5	139	11.3	104	8.5	102	8.3
11	33	2.7	50	4.1	37	3.1	37	3.0

Daily fecal coliform Load = 0.0814×10^{10} cfu/day * # of raccoon

Table A7. Monthly Distribution of Daily Muskrat Fecal Coliform Production Rate (10^{10} cfu/day)

	Nov – Feb		Mar – Apr Aug – Oct		May		June – July		Annual Average	
Sub-Water-shed	# of muskrat	Daily Load	# of muskrat	Daily Load	# of muskrat	Daily Load	# of muskrat	Daily Load	# of muskrat	Daily Load
1	59	0.3	147	0.8	265	1.4	295	1.6	152	0.8
2	117	0.6	292	1.6	526	2.9	585	3.2	302	1.6
3	68	0.4	170	0.9	307	1.7	341	1.9	176	1.0
4	4	0.0	10	0.1	19	0.1	21	0.1	11	0.1
5	28	0.2	71	0.4	127	0.7	141	0.8	73	0.4
6	118	0.6	295	1.6	531	2.9	590	3.2	305	1.7
7	150	0.8	374	2.0	673	3.7	748	4.1	387	2.1
8	49	0.3	123	0.7	221	1.2	245	1.3	127	0.7
9	17	0.1	42	0.2	75	0.4	84	0.5	43	0.2
10	86	0.5	215	1.2	387	2.1	430	2.3	222	1.2
11	30	0.2	74	0.4	133	0.7	148	0.8	76	0.4

Daily Fecal Coliform Load = 0.005446*(10^{10} cfu/day)* # of muskrat

Table A8. Monthly Distribution of Daily Beaver FC Production Rate (10^6 cfu/day)

	Oct - Mar		Apr - May		Jun – Sep		Annual average	
Sub-Water-shed	# of beaver	Daily Load	# of beaver	Daily Load	# of beaver	Daily Load	# of beaver	Daily Load
1	10	2.1	35	7.0	17	3.4	17	3.3
2	20	3.9	66	13.1	32	6.3	31	6.3
3	14	2.9	48	9.6	23	4.6	23	4.6
4	1	0.2	3	0.5	1	0.2	1	0.2
5	4	0.8	14	2.8	7	1.3	7	1.3
6	21	4.2	70	13.9	34	6.7	33	6.7
7	28	5.5	92	18.4	44	8.9	44	8.8
8	9	1.8	31	6.1	15	2.9	15	2.9
9	4	0.8	14	2.7	7	1.3	7	1.3
10	18	3.6	59	11.9	28	5.7	28	5.7
11	6	1.2	20	4.0	10	1.9	9	1.9

Daily Fecal Coliform Load = 0.2 * (10^6 cfu/day)* # of beaver

Appendix B: Summary of Assumptions for Fecal Coliform Bacteria from Wildlife and Livestock

Table B1. Summary of Fecal Coliform Load Assumptions for Livestock and Wildlife. (Source codes listed at end of Appendix B.)

Animal	Waste Load (g/day/animal)	Source	Fecal Coliform Concentration (cfu/g)	Source	Daily Production (10^6 cfu/day)	Source
Beef cow	21050	3	45500	9	985	9,10
	18144	5	1143000	14	20739*	14,10
	21050	3	4940000	5	103987	2,10
					33000	11
			230000	7		
			120000	13		
	21050	3	371654	8	7823	10
			65 to 8000000	14		
Horse	23130	3	185000	9	4279	9,10
	18598	5	12600	7	234	14,10
			6400	14		
			1300000	13		
			23000	5		
					420*	4
	20864	1	53688	8	1120	10
			100 to 25000	14		
Goat[1]	2590	3	11000000	2	28490*	10
	2590	3	15000	9	39	9,10
Sheep	1090	3	15000	9	16	9,10
			11000000	2		
Dog	450	12	2200000	9	990	9,10
			45000	14		
			23000000	14		
	500	6			1150	6
					1070*	1
Cat	19.4	9	26	9	0.0005	9,10
Deer	772	9,14	3300000	9	2548	9,10
	772	9,10	10000000	13	7720*	10
	772	9,10	450000	14	347	14,10
			170	14		
Goose	225	9	320	9	.07	9,10
	163	14	800000	14	130	14,10
	225	9	800000	14	180	10
	225	9	7600000	13	1710*	10
			31600 to 1000000	14		
Muskrat	100	9	1900000	9	190	9,10
	100	14	250000	14	25	14,10
			340000	14		
	100	9,14	544575	8	54*	10
Beaver	200	9	<1000	14		
					0.2*	9
Raccoon	450	9	13100000	9	5895	9,10
	450	14	250000	14	113	14,10
	450	9,14	1809696	8	814*	10
			1000000000	14		

[1]Following MapTech, Inc. 2001, fecal coliform concentration assumed equal to sheep

*Value used in the Moore's Creek TMDL.

Table B2. Summary of percentages of time in and around stream for wildlife used in Virginia fecal coliform TMDLs. (Note some studies defined a time in and around stream, some defined percentage waste to stream, and some were not specific. All values summarized here.)

Animal	Percentage time near stream	Source
Deer	5	9
	1*	11
Goose	50	9
	25*	11
Muskrat	90	9
	50	11
	45*	
	25	15
Beaver	100*	9
	90	11
Raccoon	5*	9
	10	11

*Value used in the Moore's Creek TMDL

Source Codes:

1 Arithmetic mean of above
2 ASAE 1998
3 ASAE (1998) as cited in MapTech, Inc. 2001
4 ASAE (1998) as cited in Virginia Tech 2000c
5 ASAE (1998) as cited in Yagow 2001
6 CH2MHill 2000
7 Geldreich (1977) as cited in Yagow 2001
8 Geometric mean of above
9 MapTech, Inc. 2001
10 Product of waste load and fecal coliform concentration/1000000
11 Virginia Tech 2000c
12 Weiskel (1996) as cited in MapTech, Inc. 2001
13 Wiggins 2001a
14 Yagow 2001
15 Virginia Tech 2000b

Appendix C: Values of Parameters in the Moore's Creek Model

Table C1. Values of parameters in the Moore's Creek model

Parameter	Definition	Units	Typical		Possible		Calibration	Function of …
			Min	Max				
PERLND Parameters								
PWAT-PARM2								
FOREST	fraction forest cover	none	0	0.5	0	0.95	1 forest, 0 others	Forest cover
LZSN	lower zone nominal storage	inches	3	8	2	15	10 forest, 9 others	Soils, climate
INFILT	index to the infiltration capacity	in/hr	0.01	0.25	0.001	0.5	0.08 forest, 0.07 others	Soils, land use
LSUR	length of the assumed overland flow plane	feet	200	500	100	700	300	Topography
SLSUR	slope of the assumed overland flow plane	none	0.01	0.15	0.001	0.3	0.1	Topography
KVARY	groundwater recession variable	1/inch	0	3	0	5	0	Baseflow recession variation
AGWRC	base groundwater recession	none	0.92	0.99	0.85	0.999	0.95	Baseflow recession
PWAT-PARM3								
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	Climate, vegetation
PETMIN	Temp below shich Et is set to zero	deg. F	30	35	30	40	35	Climate, vegetation
INFEXP	Exponent in infiltration equation	none	2	2	1	3	2	Soils variability
INFILD	Ratio of max/mean infiltration capacities	none	2	2	1	3	2	Soils variability
DEEPFR	Fraction of GW inflow to deep recharge	none	0	0.2	0	0.5	0.35	Geology, GW recharge
BASETP	Fraction of remaining ET from baseflow	none	0	0.05	0	0.2	0.03	Riparian vegetation
AGWETP	Fraction of remaining ET from active GW	none	0	0.05	0	0.2	0	Marsh/wetlands extent
PWAT-PARM4								
CEPSC	Interception storage capacity	inches	0.03	0.2	0.01	0.4	monthly	Vegetation type/density, land use
UZSN	upper zone nominal soil moisture storage	inches	0.1	1	0.05	2	1.8 forest, 1.6 others	Surface soil conditions, land use
NSUR	Manning's n (roughness) for overland flow	none	0.15	0.35	0.05	0.5	0.2	Surface conditions, residue, etc.
INTFW	Interflow inflow parameter	none	1	3	1	10	1.5	Soils, topography, land use
IRC	Interflow recessoin parameter	none	0.5	0.7	0.3	0.85	0.6	Soils, topography, land use
LZETP	Lower zone ET parameter	none	0.2	0.7	0.1	0.9	monthly	Vegetation type/density, root depth
QUAL-INPUT								
ACQOP	Rate of accumulation of constituent	#/day					monthly	Land use
SQOLIM	Maximum accumulation of constituent	#					9 x ACQOP	Land use
WSQOP	Wash-off rate	in/hr					1.1	Land use
IOQC	Constituent conc. in interflow	$\#/ft^3$					1416	Land use
AOQC	Constituent conc. in active groundwater	$\#/ft^3$					1416	Land use

Table C1 (cont.)

Parameter	Definition	Units	Typical		Possible		Calibration	Function of …
			Min	Max				
IMPLND Parameters								
IWAT-PARM 2								
LSUR	length of overland flow	ft	50	150	50	250	200	Topography, drainage system
SLSUR	slope of overland flow plane	ft/ft	0.01	0.05	0.001	0.15	0.05	Topography, drainage
NSUR	Manning's n for overland flow	none	0.03	0.1	0.01	0.15	0.1	Impervious surface conditions
RETSC	Retention storage capacity	inches	0.03	0.1	0.01	0.3	0.1	Impervious surface conditions
IWAT-PARM 3								
PETMAX	Temp below which ET is reduced by half	deg. F	35	45	32	48	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	Climate, vegetation
IQUAL								
ACQOP	Rate of accumulation of constituent	#/day					3.5E+07 to 5.0 E+09	Land use
SQOLIM	Maximum accumulation of constituent						2 x ACQOP	Land use
WSQOP	Wash-off rate	in/hr					0.5	Land use
RCHRES Parameters								
HYDR-PARM2								
KS	Routing weighting factor	none	0	0.5	0	0.99	0.5	Channel slope, flow obstructions
GQUAL								
FSTDEC	First order decay rate of the constituent	1/day					1.15	
THFST	Temperature correction coeff. for FSTDEC						1.05	

Appendix D: Calculation of Grassland Loading Rates for Calibration Period and 2002.

For comparison purposes the grassland loading rates for both and calibration period and 2002 are derived. Table D.1 shows the wildlife load to grassland, which is assumed unchanged throughout the calibration period and into 2002. Tables D.2 and D.3 show the livestock loads for the calibration period; these loads are based on the average number of livestock during the calibration period.

Table D.1 Wildlife daily coliform loads to grasslands for calibration period and 2002 (10^{10} cfu/day).

SW#	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	31.2	31.2	31.5	31.5	31.8	31.9	31.9	31.5	31.5	31.5	31.2	31.2
2	6.4	6.4	6.4	6.4	6.5	6.5	6.5	6.4	6.4	6.4	6.4	6.4
3	20.8	20.8	21.1	21.1	21.4	21.5	21.5	21.1	21.1	21.1	20.8	20.8
4	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
5	24.4	24.4	24.5	24.5	24.8	24.8	24.8	24.5	24.5	24.5	24.4	24.4
6	21.0	21.0	21.2	21.2	21.5	21.6	21.6	21.2	21.2	21.2	21.0	21.0
7	39.4	39.4	39.7	39.7	40.1	40.2	40.2	39.7	39.7	39.7	39.4	39.4
8	25.4	25.4	25.6	25.6	26.0	26.0	26.0	25.6	25.6	25.6	25.4	25.4
9	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
10	16.2	16.2	16.4	16.4	16.6	16.7	16.7	16.4	16.4	16.4	16.2	16.2
11	3.4	3.4	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.4	3.4

Table D.2 (and Table 4.16) Cattle daily coliform loads to grasslands for calibration period (10^{10} cfu/day).

SW#	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	56.0	56.0	56.0	56.0	56.0	56.0	56.0	56.0	56.0	56.0	56.0	56.0
2	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4
3	111.8	111.8	111.7	111.6	111.4	110.7	110.7	110.7	111.4	111.6	111.7	111.8
4	4.1	4.1	4.0	4.0	3.9	3.5	3.5	3.5	3.9	4.0	4.0	4.1
5	89.2	89.2	89.2	89.2	89.2	89.2	89.2	89.2	89.2	89.2	89.2	89.2
6	128.6	128.6	128.6	128.6	128.6	128.6	128.6	128.6	128.6	128.6	128.6	128.6
7	180.4	180.4	180.4	180.4	180.4	180.4	180.4	180.4	180.4	180.4	180.4	180.4
8	145.2	145.2	145.2	145.2	145.2	145.2	145.2	145.2	145.2	145.2	145.2	145.2
9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9
10	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4
11	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4

Table D.3 (from Table 4.12). Horse and goat daily coliform loads during calibration period (10^{10}cfu/day).

Subwatershed	Horse	Goat
1	0.3	11.4
2	0.2	8.5
3	0.6	22.8
4	0.0	0.0
5	0.5	17.1
6	0.6	25.6
7	0.9	37.0
8	0.7	28.5
9	0.1	65.5
10	0.2	8.5
11	0.0	2.8

Table D.4 shows the livestock numbers during the calibration period and those based on the 2002 Albemarle Farm Bureau count, plus the number of animals at the stockyard above the Moore's Creek wastewater treatment plant. The Farm Bureau count did not distinguish between cattle and horses, nor did it include goats. In general, the ratio of cattle to horses was held constant within each subwatershed, except for in subwatershed 2, where all remaining large livestock were assumed to be horses at the youth camp. Only the number of goats in Subwatershed 9, with the stockyard and feral goats, was estimated for 2002. In the other subwatersheds, the 2002 goat load was assumed to be 42% of the calibration load (= number of large livestock counted by the Farm Bureau/number of large livestock used during calibration).

The fecal coliform bacteria load to grasslands during the calibration period (Table D.5) is simply the sum of the loads shown in Table D.1 to D.3. The 2002 grassland load (Table D.6) is the sum of the load in D.1 plus the loads in Tables D.2 and D.3 multiplied by the appropriate percentage in Table D.4. For instance, the January 2002 subwatershed 5 load of 66.9 x 10^{10} cfu/day is calculated as follows (24.4 + 89.2 * .395 + 0.5 * .273 + 17.1 *0.42) x10^{10} cfu/day. The loading rates are then determined by dividing the loads by the area of grassland in each subwatershed (Table 3.2). The grassland loading rates for the calibration period and 2002 are shown in tables D.7 and D.8. Based on the values in Tables D.7 and D.8, the average loading rate in 2002 is 53% of that during the calibration period. The values shown in Table D.8 are used as the base case loading rates for grasslands for the allocation period. Note that the total area of grassland, and thus the total load from grassland, will change from the 2002 level due to the land use changes described in Chapter 6.

Table D.4 Livestock populations during the calibration period and in 2002 and percentage load remaining.

	Calibration Period			2002			Percentage Remaining Load		
SW#	Beef Cattle	Horses	Goats	Beef Cattle	Horses	Goats	Beef Cattle	Horses	Goats
1	27	7	4	0	0	NA	0	0	42.0*
2	19	5	3	0	15	NA	0	300.0	42.0*
3	54	14	8	39	6	NA	72.2	42.9	42.0*
4	2	0	0	0	0	NA	0	0	42.0*
5	43	11	6	17	3	NA	39.5	27.3	42.0*
6	62	15	9	47	8	NA	75.8	53.3	42.0*
7	87	22	13	56	9	NA	64.4	40.9	42.0*
8	70	17	10	9	1	NA	12.9	5.9	42.0*
9	12	3	23	12	3	22	100.0	100.0	95.7
10	19	5	3	0	0	NA	0	0	42.0*
11	5	1	1	0	0	NA	0	0	42.0*
Total	400	100	80	180	45		45.0	45.0	

*Assumed goat load remaining

Table D.5 Daily coliform loads to grasslands for calibration period (10^{10} cfu/day).

SW#	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	98.9	98.9	99.2	99.2	99.5	99.6	99.6	99.2	99.2	99.2	98.9	98.9
2	54.6	54.6	54.6	54.6	54.6	54.6	54.6	54.6	54.6	54.6	54.6	54.6
3	156.0	156.0	156.2	156.1	156.3	155.6	155.6	155.2	155.9	156.1	155.9	156.0
4	4.8	4.8	4.8	4.8	4.8	4.7	4.7	4.7	4.8	4.8	4.8	4.8
5	131.1	131.1	131.3	131.3	131.5	131.5	131.5	131.3	131.3	131.3	131.1	131.1
6	175.9	175.9	176.1	176.1	176.4	176.5	176.5	176.1	176.1	176.1	175.9	175.9
7	257.8	257.8	258.1	258.1	258.5	258.6	258.6	258.1	258.1	258.1	257.8	257.8
8	199.8	199.8	200.0	200.0	200.3	200.4	200.4	200.0	200.0	200.0	199.8	199.8
9	98.3	98.3	98.3	98.3	98.3	98.3	98.3	98.3	98.3	98.3	98.3	98.3
10	64.3	64.3	64.5	64.5	64.8	64.8	64.8	64.5	64.5	64.5	64.3	64.3
11	16.7	16.7	16.7	16.7	16.8	16.8	16.8	16.7	16.7	16.7	16.7	16.7

Table D.6 Daily coliform loads to grasslands in 2002 (10^{10} cfu/day).

SW#	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	36.0	36.0	36.3	36.3	36.6	36.7	36.7	36.3	36.3	36.3	36.0	36.0
2	10.6	10.6	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.6	10.6
3	111.4	111.4	111.6	111.5	111.8	111.3	111.3	110.9	111.4	111.5	111.3	111.4
4	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
5	66.9	66.9	67.1	67.1	67.3	67.4	67.4	67.1	67.1	67.1	66.9	66.9
6	129.6	129.6	129.8	129.8	130.1	130.2	130.2	129.8	129.8	129.8	129.6	129.6
7	171.5	171.5	171.8	171.8	172.2	172.3	172.3	171.8	171.8	171.8	171.5	171.5
8	56.1	56.1	56.3	56.3	56.6	56.7	56.7	56.3	56.3	56.3	56.1	56.1
9	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4	95.4
10	19.8	19.8	20.0	20.0	20.2	20.3	20.3	20.0	20.0	20.0	19.8	19.8
11	4.6	4.6	4.6	4.6	4.7	4.7	4.7	4.6	4.6	4.6	4.6	4.6

Table D.7 Daily coliform loading rate to grasslands during calibration period (10^{8} cfu/acre/day).

SW#	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	18.9	18.9	18.9	18.9	19.0	19.0	19.0	18.9	18.9	18.9	18.9	18.9
2	50.6	50.6	50.6	50.6	50.7	50.7	50.7	50.6	50.6	50.6	50.6	50.6
3	44.7	44.7	44.8	44.8	44.8	44.6	44.6	44.5	44.7	44.8	44.7	44.7
4	43.4	43.4	43.5	43.4	43.4	42.6	42.6	42.2	43.2	43.4	43.3	43.4
5	32.0	32.0	32.0	32.0	32.1	32.1	32.1	32.0	32.0	32.0	32.0	32.0
6	49.9	49.9	50.0	50.0	50.1	50.1	50.1	50.0	50.0	50.0	49.9	49.9
7	38.9	38.9	39.0	39.0	39.0	39.1	39.1	39.0	39.0	39.0	38.9	38.9
8	46.8	46.8	46.9	46.9	47.0	47.0	47.0	46.9	46.9	46.9	46.8	46.8
9	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3	75.3
10	23.7	23.7	23.8	23.8	23.9	23.9	23.9	23.8	23.8	23.8	23.7	23.7
11	29.2	29.2	29.3	29.3	29.4	29.5	29.5	29.3	29.3	29.3	29.2	29.2

Table D.8 Daily coliform loading rate to grasslands in 2002 (10^{8} cfu/acre/day).

SW#	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	6.9	6.9	6.9	6.9	7.0	7.0	7.0	6.9	6.9	6.9	6.9	6.9
2	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9
3	32.0	32.0	32.0	32.0	32.1	31.9	31.9	31.8	32.0	32.0	31.9	32.0
4	6.1	6.1	6.3	6.3	6.6	6.6	6.6	6.3	6.3	6.3	6.1	6.1
5	16.3	16.3	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.3	16.3
6	36.8	36.8	36.8	36.8	36.9	37.0	37.0	36.8	36.8	36.8	36.8	36.8
7	25.9	25.9	25.9	25.9	26.0	26.0	26.0	25.9	25.9	25.9	25.9	25.9
8	13.1	13.1	13.2	13.2	13.3	13.3	13.3	13.2	13.2	13.2	13.1	13.1
9	73.1	73.1	73.1	73.1	73.1	73.1	73.1	73.1	73.1	73.1	73.1	73.1
10	7.3	7.3	7.4	7.4	7.4	7.5	7.5	7.4	7.4	7.4	7.3	7.3
11	8.1	8.1	8.2	8.2	8.3	8.3	8.3	8.2	8.2	8.2	8.1	8.1

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